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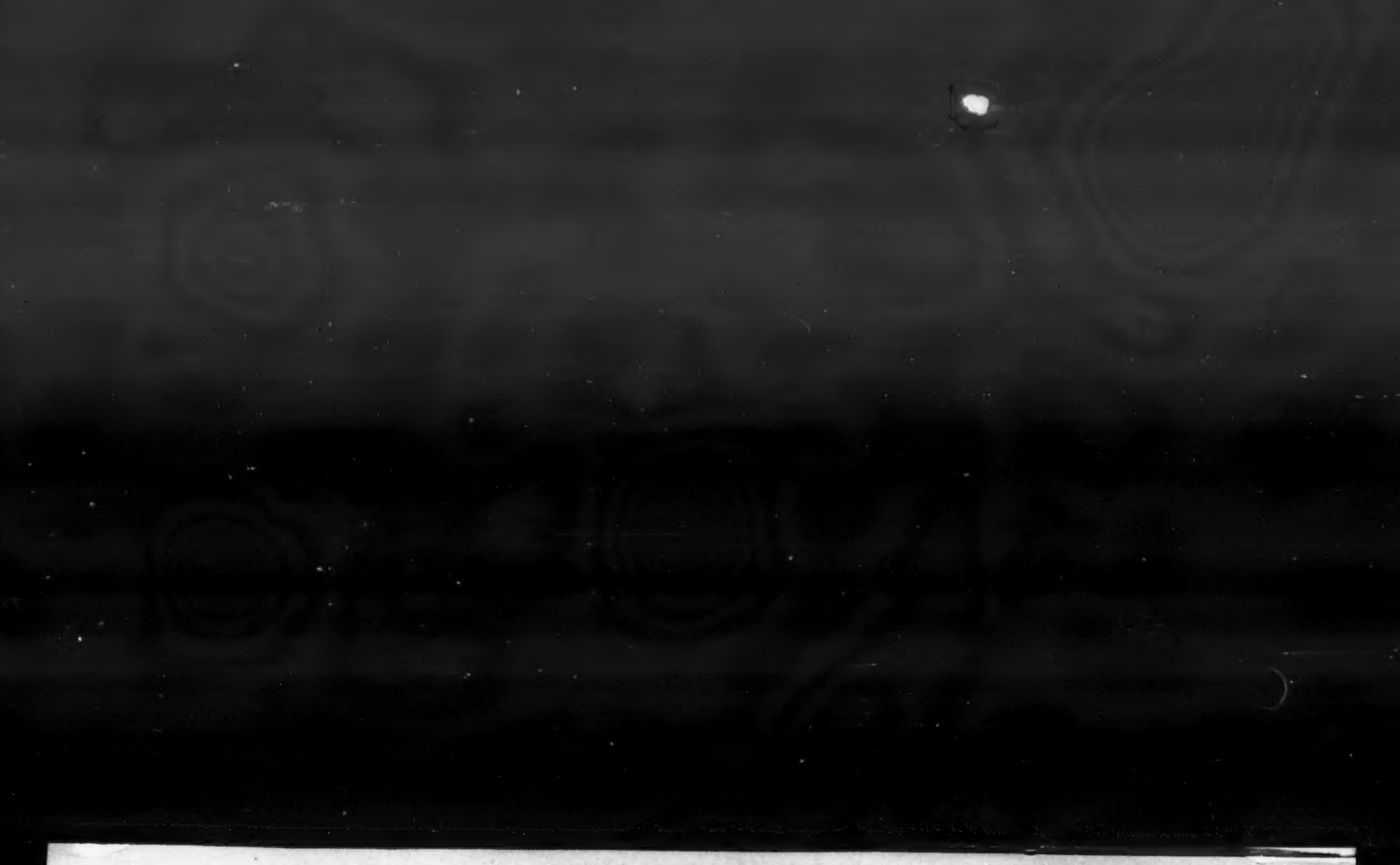


THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. VI.—*On Wollastonite and Psuedo-Wollastonite,—Polymorphic Forms of Calcium Metasilicate;* by E. T. ALLEN and W. P. WHITE, with optical study by FRED. EUGENE WRIGHT.

[By permission of the Director of the U. S. Geological Survey.]*

Introductory.†—Wollastonite is said to occur in massive rocks as an original constituent, but is perhaps confined to nepheline syenite such as is described from Alnö by Törnebohm, who found it as inclusions in feldspar, in nepheline and in ægirine. Similar rocks have been described by Mügge and others. It is also not uncommon in the crystalline schists. In some such cases, like that described by Cross from Brittany, the wollastonite is a secondary product and forms pseudomorphs after plagioclase. Among the crystalline limestones of the ancient schist series it is abundant, and it is found also in related rocks of the same series, such as garnetite and calcareous slates. Heinrich Wulf‡ has also described it as an original constituent of the crystalline schists in Hereroland in Southwest Africa, and one of his rocks consists of nearly equal parts of wollastonite and diopside.

Wollastonite is most abundant in and most characteristic of contact metamorphic limestones, either along the periphery of massives or in fragments included in a variety of eruptive rocks. It is thus usually classed as a contact mineral. It often forms well-shaped crystals of visible size, but no pseudo-wollastonite

* This paper was prepared with the aid of a grant from the Carnegie Institution of Washington for this purpose.

† For the introductory paragraphs upon the natural occurrence of wollastonite, the authors are indebted to Dr. George F. Becker.

‡ Min. Petr. Mitth., viii, 230, 1887.

is known in nature nor any paramorph of wollastonite after pseudo-wollastonite. On the other hand, pseudo-wollastonite in crystals no less than a centimeter in width has been observed in artificial slags by Vogt and others.

Had the schists containing wollastonite crystallized at temperatures above 1180°, it would seem from the following investigation that the calcium silicate must have separated out as pseudo-wollastonite, and that even had it afterwards gone over by paramorphism into wollastonite, the original form must have left its traces. Such, too, must have been the case had the contact metamorphosis of limestones taken place at a higher temperature or had the fragments of limestones, often very small, which are included in effusive rocks, been heated above this critical temperature. Such included fragments are often sharply angular, and there is no probability that they were ever melted. Of course, the character of a melt is greatly modified by the constituents present, so that the admixture of other substances than calcium silicate must be taken into account; but it would appear that other substances, such as iron compounds, could only reduce the melting temperature of the mixture, making it safe to conclude that wollastonite can under no circumstances have formed above 1180°. The effect of pressure is probably without influence upon this conclusion in view of the very low vapor tension of the mineral at its inversion temperature. The present investigation therefore adds a very considerable amount of exactness to our knowledge of the temperatures at which the metamorphism of limestone has gone on. If the wollastonite of the nepheline syenite is primitive, at least one family of deep-seated intrusives has also been injected at temperatures lower than 1180°.

Messrs. Day and Shepherd have shown that wollastonite is very generally stable, and apt to make its appearance under a wide range of circumstances from melts of very different compositions. This, too, is in entire accord with the geological evidence afforded by contacts along which the chemical conditions vary greatly and rapidly, while wollastonite, through its frequency, exhibits, in nature as well as in the laboratory, a strong tendency to form under varying conditions.

Preparation of Wollastonite.—Attempts to synthesize the mineral wollastonite ($CaSiO_3$) generally result in the formation of a substance, apparently uniaxial, which has never been found in nature. Even when the natural wollastonite is fused and cooled again, it is almost invariably the uniaxial form which crystallizes. The genuine wollastonite has been observed as an accidental product of slow cooling in glasses, and crystals

of it, in a few instances,* have been obtained by intention from artifical magmas, usually without any clear insight into the causes of its formation. Hussak† obtained it as one of the products from a mixture of silicates and borates of calcium and sodium; Doelter‡ from a magma made of lime and silica with fluorides of calcium and sodium. Methods of this kind will evidently yield mixtures more or less complex of which wollastonite is only one constituent and in which the experimenter is confined entirely to optical methods for the examination and identification of the mineral.

In connection with an extended study of the pyroxenes, it was our purpose to prepare wollastonite, determine its properties, and discover, if possible, its relation to the artificial form.

Suspecting that temperature was the determining factor,§ we first prepared a glass of the composition $CaSiO_3$, and by heating this at a temperature of 800° to 1000° succeeded in getting true wollastonite in pure condition and in portions of 50 grams at a time. The glass, to be sure, is a little difficult to prepare on account of the strong tendency of the liquid to crystallize. Although once we obtained 100 grams of it by simply cooling in the furnace where it was melted, it almost always crystallizes prematurely when thus treated. The safest way is to melt smaller portions and then chill suddenly in cold water.

For the preparation of the glass, we used the purest quartz and calcium carbonate obtainable. The latter contained only a few hundredths of a per cent of alkali and magnesium, the quartz, about two-tenths of one per cent of total impurities, chiefly oxide of iron. The ingredients were weighed in exact proportions and melted in a platinum crucible. It requires over 1500° to melt this mixture, a temperature readily reached by a Fletcher gas furnace.‖ When the contents of this crucible are quite fluid, the crucible is seized with tongs and plunged into cold water, care being taken not to agitate the liquid silicate. In this way, one obtains a brilliant colorless glass. Frequently a portion will crystallize in spite of the efforts of the operator, but if the quantity is small and not too much scattered, it can be separated mechanically from the glass with little trouble. The glass needs now only to be heated in a platinum crucible over the flame of a Bunsen burner, when it crystallizes directly and quite rapidly to wollastonite.

* Morozewicz, N. Jahrb. f. Min. 1894, ii, 223. Vogt, Die Silikatschmelzlösungen i, p. 45.

† Hussak, Zeitschr. für Kryst. und Min., xvii, 101.

‡ Doelter, Tschermak's Mitt. Petr. Mitth., x, 83, 1888.

§ Doelter has also expressed this view. N. Jahrb. f. Min. Referate, 1886, i, 123.

‖ 4la—Buffalo Dental Mfg. Co.

Properties.—The pure mineral is white in the mass and shows when prepared by the process just described the fibrous structure which is commonly characteristic of the natural mineral. A perfectly transparent variety in beautifully formed crystals of short prismatic habit was obtained later in an entirely different manner, which will be described subsequently. A detailed microscopic study of both varieties by Mr. Wright accompanies this paper.

The density of the fibrous material varies considerably, being dependent on the temperature of crystallization, and perhaps upon other conditions. The variation is satisfactorily accounted for by the presence of bubbles, or more probably vacuous spaces, which the microscope shows are generally present in the crystalline mass. They are probably the residual spaces which are left by the condensation of substance about the crystal nuclei. In one of the preparations, Prep. IV, which in crystallizing almost reached the inversion point, these bubbles were not found, and the crystalline fibers were much coarser. The following determinations were made by the method of Day and Allen:*

Specific Gravity of Fibrous Wollastonite, prepared by the devitrication of the glass. Determinations were made at 25° and compared with water at 25°.

Prep. I.	Heated about 3 days at a maximum temperature of 860°.	2·907 2·907
Prep. II.	Heated 17 hours at a maximum temperature of 950°.	2·876 2·876
Prep. III.	Heated 22 hours at a maximum temperature of 980°.	2·896 2·896
Prep. IV.	Formed from an under-cooled mass which began to crystallize at 1030° and rose in the process to a temperature of 1127°. The microscope showed a coarsely fibrous mass without the bubbles which appeared in I, II and III.	2·9145 2·9156 2·915

The density of the glass from which the wollastonite is prepared is here given for purposes of comparison. The glass is perfectly free from bubbles and hence shows a practically constant density, which differs but little from that of wollastonite, being a trifle lighter than the densest preparation.

Specific Gravity of Glass of the Composition $CaSiO_3$, determined at 25°, compared with water at 25°.

Prep. *a*.	Prep. *b*.	Prep. *c*.
2·901	2·905	2·905
2·902	2·905	2·903

* Isomorphism and Thermal Properties of the Feldspars, this Journal, xix, 125, 1905. Publication No. 31, Carnegie Institution of Washington, p. 55.

The Inversion of Wollastonite to Pseudo-Wollastonite.—It is sufficiently well known that the polymorphic forms of solid crystalline bodies are divided into two well-marked classes, the monotropic and the enantiotropic. Substances which, like phosphorus, belong to the first class, possess one form which is more stable than the other at all temperatures below the melting point. The unstable form may therefore change directly into the other over a considerable range of temperature, but the change in the opposite direction cannot be brought about. In substances of the second class, the enantiotropic bodies, the transformation from one to the other takes place at a characteristic temperature point, known as the inversion point, and is reversible. Each form of a monotropic substance possesses its own melting point, while in enantiotropic substances only one form melts in the region of its stable existence, viz: that form which is stable at the higher temperature.*

In calcium silicate we have unquestionably a case of enantiotropy, for one form changes to the other at a definite temperature, and the change is, under proper conditions, reversible.

When wollastonite, either natural or artificial, is heated to about 1180°, it passes entirely into the hexagonal form. This change of state occurs without melting, for, in every case, the coarsely-powdered mineral which we employed in experiment was found, after the inversion, to have shrunk away from the walls of the crucible, forming a sintered cake, which, of course, a liquid could never have done. Moreover, the separate grains of the substance always preserved their sharp edges.

Brun† states that natural wollastonite from Auerbach melts at about 1350° and then quickly solidifies. There is, of course, the possibility that a rapidly heated charge might pass the inversion point without change and melt in the metastable region, as sulphur is known to do. A special effort was made to test this possibility in the following manner: a 50 gram charge of the purest natural wollastonite obtainable (from Diana, N. Y.) was heated in the electric furnace past the inversion point at the fastest rate consistent with the safety of the heating coil, i. e., about 16° per minute. To hinder inversion as much as possible, we selected rather large fragments of the mineral with comparatively little surface. At 1260° a perceptible absorption of heat was observed, immediately after which the temperature was lowered and the charge examined. Some fragments had undergone a slight local vitrification which gave the effect of glazing, but the original form of each

* Roozeboom, Heterogene Gleichgewichte, vol. i, pp. 109, 110. Findlay, The Phase Rule, 1904, p. 42.

† Archives des Sciences phys. et nat., série 4e, tome 18, p. 551.

was preserved down to the corners and edges, which remained as sharp as ever, and the microscope proved that all had been converted into pseudo-wollastonite. We were therefore unable to reproduce Brun's results or to explain them.

To locate the inversion point, we experimented in two different ways. On the one hand, we established a point below which inversion would not occur, by heating powdered wollastonite in contact with the hexagonal form at measured temperatures for more or less protracted intervals. At a temperature of 1100° there was no sign of inversion after a period of 60 hours. We relied upon microscopic evidence for our conclusion.*

A charge made up in the same way and held at 1170° for an hour likewise showed no indication of change, but the same charge returned to the furnace and kept at 1190° for another hour showed that the transformation had begun. The change revealed itself in the formation of small grains and patches of pseudo-wollastonite, embedded in the original wollastonite, which were plainly visible between crossed nicols. 1190° is therefore the lowest temperature at which we can certainly say that inversion takes place. Changes in the solid state are well known to be very sluggish, and this one, as will appear farther on, is a rather extreme case. It may therefore well be that if experiments were continued for very long periods, the true inversion temperature would be found to fall somewhat lower down.

By the use of Frankenheim's method,† in which the temperature is observed at regular intervals as heat is continually supplied to the mass, we were able to detect a small absorption of heat corresponding to the physical change revealed by the microscope.

A departure from previous practice was made in the use of a control element. The heating of a furnace can not be made perfectly regular even with storage batteries of large capacity, but the temperature rises with continual slight fluctuations, which, of course, are shared by the charge in the crucible, where they are indistinguishable in their effect on a thermo-element from slight evolutions or absorptions of heat in the charge itself. The control element, which gives the temperature of the furnace, enables a correction to be applied for the furnace fluctuations. It is read alternately with the element in the charge. In general, it is not easy to tell exactly what effect upon the charge is produced by a given fluctuation in

* For the examination of these mixtures the authors are indebted to Mr. W. Lindgren of the U. S. Geological Survey.

† Day and Allen, Isomorphism and Thermal Properties of the Feldspars, this Journal, xix, 93, 1905; Publication No. 31, Carnegie Institution of Washington.

the furnace, but the average difference of temperature between the two elements measures the rate at which heat is passing into the crucible, and any change in this difference shows an absorption or evolution of heat, provided that no great change in the average rate of heating has occurred.

INVERSION OF WOLLASTONITE.

Rate of heating in degrees per minute.	Inversion temperature.
8·8	1232
3·6	1225 (See curve 1, Table I.)
1·0	1198
1·1	1197 (See Table II.) Mixed with inverted form.
1·0	1211 Mixed with inverted form.

These results indicate, in harmony with the microscopic evidence, that the presence of the inverted form has, under the given conditions, little or no effect on the inversion. That the inversion temperature should seem to be higher as the rate of heating increases, was to be expected. The last sample was carried as far as 1245°, and on cooling was found to be inverted only in part.

The Reversion of Pseudo-Wollastonite.—When pure pseudo-wollastonite was cooled, even very slowly, it did not revert to wollastonite. Our first efforts to overcome this inertia were along the usual lines. We added to the mass a small quantity of the more stable phase (wollastonite) and allowed plenty of time for equilibrium to assert itself. The two forms, mixed in about equal proportions, were spread in a thin layer at the bottom of a platinum crucible, and on this was placed a deeper layer of the pseudo-wollastonite. Experiments lasting from 36 to nearly 60 hours at temperatures ranging from 900° to 1100° were without effect; the optical method of identification always showed both substances and indicated no change whatever. We next tried the effect of the solvent action of water. The two forms, mixed as we have described above, were heated for several days in a steel bomb with water above its critical temperature. The bomb held tight, but there was no indication of change in the crystals. We will not therefore describe the apparatus and the conditions of experiment in detail. Both crystalline forms were proved by the microscope to be practically unchanged by this treatment, and chemical tests showed little hydrolysis. This is somewhat surprising in view of the fact that these silicates impart an alkaline reaction to water on standing in the cold. It should be remarked that the quantity of water used was very small, only 3 to 4 cc. to 2 gr. of substance. On the glass

TABLE I.

Inversion.

Curve I.

Control.	Rise in 2 min.	Crucible.	Rise in 2 min.	Diff.
11481				
	92	11360		167
573			92	
	93	452		167
666			93	
	94	545		168
760			94	
	90	639		166
850			91	
	92	730		166
942			90	
	98	820		171
12040			92	
	96	912		176
136			99	
	91	12011		170
227			90	
	89	101		170
316			82	
	90	175		188
406			59	
	96	**232**		222
502			79	
	98	311		240
600			124	
	95	435		213
695			121	
	96	556		189
791			114	
	97	670		170
888			105	
	97	775		162
985			101	
	84	876		151
13079			98	
	92	974		151
171			96	
	97	13070		150
268				

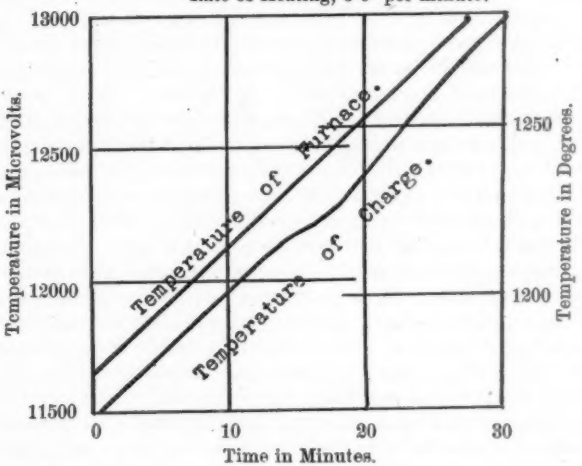
TABLE II.

Inversion.

20 per cent of the inverted form was mixed with the charge so as to start the action at the lowest possible temperature.

Control.	Rise in 2 min.	Crucible.	Rise in 2 min.	Diff.
11795				
	62	11662		133
857			62	
	59	724		133
916			58	
	57	782		134
944			54	
	56	836		134
12000			55	
	60	**891**		137
060			59	
	56	950		139
116			56	
	54	12006		136
170			55	
	54	061		137
224			53	
	51	114		136
275			50	
	49	164		134
324			52	
	51	216		132
375			54	
		270		128

CURVE I.—Inversion of Wollastonite.
Inversion Temperature, 1225°.
Rate of Heating, 3·6° per minute.



there were signs of some action. The grains were cemented tightly together, while the microscope disclosed what appeared to be an incipient crystallization.

From water we turned to the solvent action of a fused salt.* The necessary properties in a salt which should answer our purpose are evidently the possession of an ion common to calcium silicate, so that metathesis may not result; sufficient fusibility, and sufficient solubility, in order that the excess may be removed after the process is complete.

These requirements are fulfilled by calcium vanadate, $Ca(VO_3)_2$, which is prepared by heating calcium carbonate with the proper proportion of vanadic acid. In the first trial, we heated one gram of vanadate with several grams of pseudo-wollastonite at a temperature of 800° to 900° for a number of days. The solvent was then partially extracted by hot water, after which the residue, so far as possible, was removed by very dilute hydrochloric acid. The product was all changed into wollastonite. In later experiments, we tried larger quantities of vanadate and heated for different periods. One gram of vanadate readily transforms 5 grams of silicate and is removed when the change is accomplished with less trouble than a

* Calcium chloride forms chloro-silicates. Gorgeu, Bull. Soc. Min., x, 271. In our experiments we did not get a pure product, though the majority of it, when a large excess of calcium chloride was used, crystallized in transparent lath-like crystals of orthorhombic (?) symmetry. The ratio of chlorine to silica in the product was in accord with the formula $2CaSiO_3.CaCl_2$.

larger quantity. The mass thus formed is scarcely pasty at the highest temperature of an ordinary Bunsen burner, yet the yellow color shows that the silicate is completely permeated by the vanadate. If one desires as large crystals as possible, it is well to take more vanadate and heat for a longer time. To get the silicate in pure condition, it is best to break up the fused mass in a mortar, with a little water, cover it with, say, 50 to 100 cc. cold water, and then add a few drops of dilute hydrochloric acid, stirring thoroughly. After a few minutes, pour off the water and repeat the treatment until the water is no longer colored yellow. In this way the calcium vanadate is decomposed and removed more readily than with water alone, while if one keeps the acid cold and very dilute, the silicate is not decomposed to any extent, and the microscope shows the product to be unmixed with foreign matter. It consists, as stated above, entirely of wollastonite in beautiful transparent crystals of short prismatic habit, with sharp edges and well developed faces. The largest were about 0·2 mm long.

This formation of wollastonite could hardly be anything else than a true reversion. It is well known that such transformations in solid bodies may be facilitated by the use of solvents which probably overcome resistance to molecular movement. In this case, at the temperature of 800 to 900°, wollastonite should be the more stable polymorph, possessing a lower vapor pressure and a lower solubility. Given a nucleus of this form, therefore, the other should pass into solution and continually precipitate in the form of wollastonite. That this is really what happens, we proved by stopping the transformation before it was complete (5 grams silicate to 1 gram vanadate heated three hours). Large grains of pseudo-wollastonite remained unchanged except for a rounding of corners and edges, and side by side with them appeared small well-formed crystals of wollastonite.

As these crystals, on account of their freedom from bubbles or pores, seemed especially adapted for the determination of density, two separate preparations were made for this purpose.

	Prep. I. Sp. gr. 2·914. Analysis.	Prep. II. Sp. gr. 2·912. Analysis.	Cal. for $CaSiO_3$
SiO_2	51·94	52·00	51·86
CaO	47·69	47·46	48·14
Fe_2O_3 etc.	·19	·18	----
V_2O_4*	·38	·49	----

* Both preparations had a pale blue tint, which led us to suspect that the vanadium had been reduced in the process of heating over the gas flame to the blue oxide V_2O_4.

These numbers show very satisfactory agreement with the specific gravity 2·915 of the wollastonite which crystallized from an under-cooled melt, and may be regarded as the true specific gravity of pure wollastonite.

Some further light has been thrown on the formation of wollastonite by the unpublished work of Messrs. Day and Shepherd of this laboratory. They have examined the entire series of lime-silica mixtures and have obtained wollastonite easily in a variety of mixtures. There appears to be little difficulty in obtaining true wollastonite as soon as an excess of either component is present in the charge. The metasilicate first crystallizes in the hexagonal form, but the inversion to wollastonite occurs during cooling with little or none of the difficulty which we encountered in pure $CaSiO_3$ preparations. True wollastonite can, in fact, be obtained more readily out of concentrations with a slight excess of CaO than by the use of vanadic acid, but the crystals so formed are not large enough for convenient microscopic study, and cannot be readily separated.

In accord with nearly all of our laboratory experiments, both crystallization and inversion go on more slowly in the presence of an excess of silica, due probably to mechanical inertness or viscosity.

Pseudo-Wollastonite.—This form may be obtained by heating wollastonite above 1180°, or by crystallizing a melt above this temperature. It is only rarely that anything but pseudo-wollastonite is obtained on cooling a melt, but to insure its formation the melt needs only to be slightly agitated to overcome the instability. Pseudo-wollastonite has been described optically by Bourgeois.* It shows a basal cleavage, is optically positive, and very nearly uniaxial, though Bourgeois regards it as really monoclinic. Doelter† combats this view, but Mr. Wright in the microscopic part of this paper finds additional arguments in support of it. It crystallizes, under such conditions as have obtained in our experiments, in fibrous, fan-shaped aggregates. The density of the inverted but still unmelted crystals is variable, owing, no doubt, to the presence of bubbles, and not to be distinguished with certainty from the wollastonite, showing again that the volume change which accompanies the inversion is very small.

SPECIFIC GRAVITY OF WOLLASTONITE AT 25° COMPARED WITH WATER AT 25°.

1. Inverted but not melted.	2. Inverted but not melted.	3. Melted.
2·886	2·896	2·913
2·886	2·896	2·912

* Bull. Soc. Min., v, 14–15.

† N. Jahrb. f. Min., 1886, i, 120 and 122.

Melting Point of Pseudo-Wollastonite.

This was determined in practically the same way as the inversion, except that some of the readings were made every half minute. The rates of heating varied between 2·1 and 2·7° per minute.

	First Sample. Four Meltings.	
	Microvolts.	Degrees.*
El H	16058	1511·0
	16065	1511·5
	16062	1511·3
	16073	1512·1

	Second Sample. One Melting.		
	Microvolts.	Degrees.	
El G	16053	1512·0	(curve 3.)
El L	16072	1512·1	

	Third Sample. One Melting.	
	Microvolts.	Degrees.
El G	16060	1512·7

	Fourth Sample. Two Meltings.	
	Microvolts.	Degrees.
El F	16104	1513·5
	16104	1513·5

Melting point, 1512.

Summary and Conclusions.

1. Wollastonite and pseudo-wollastonite are enantiotropic forms of calcium metasilicate, showing an inversion point at about 1180°. The change $W_n \longrightarrow W_p$† is easily effected by heating above this temperature, while the reverse change has not been accomplished without the addition of other substances, owing to the sluggish nature of the silicate. Cases of suspended transformation are common enough, but a reversion which fails altogether even after heating for days in contact with the stable form is remarkable. We may compare it to the case of the glasses of the alkaline feldspars, which resist all attempts to make them crystallize by heating and sowing with nuclei. The fact very well illustrates one of the difficulties which the experimenter constantly encounters in the study of

* Fractions of degrees are given in order to show the agreement obtainable in such determinations. The absolute value of the melting point is dependent upon the thermoelectric extrapolation of the gas scale, and is subject to correction whenever the latter shall be extended to this point.

† Let W_n represent the optically negative form, and W_p the positive.

TABLE III.*

Melting of Pseudo-Wollastonite. Curve 2.

Control.	Rise in 2 min.	Melt.	Rise in 2 min.	Rise in ½ min.	Control.	Rise in 2 min.	Melt.	Rise in 2 min.	Rise in ½ min.
15616					16109			33	8
							15993		8
	72	15604				66	16001		7
							008		7
688			70		175			27	6
							021		7
	72	674				70	028		6
							034		6
760			66		245			26	7
							047		7
	76	740				70	054		6
							060		7
836			66		315			28	7
							074		8
	77	806				65	082		10
							092		12
913			62		380			69	16
							126		25
	74	868				90	151		32
							183		
987			55		470			247	
	59	923				108	398		
			45		578				
16046	63	968		9					
		977		8					

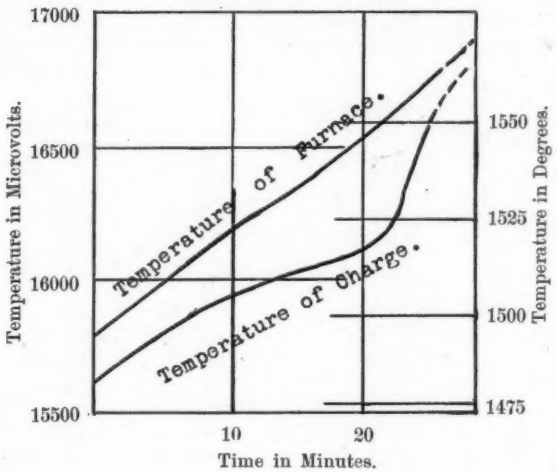
the silicates. Molten calcium vanadate brings about the reversion at temperatures below the inversion point by the formation of a solution from which the more stable wollastonite crystallizes in well-formed prismatic crystals. Excess of lime or silica also facilitates the reversion.

Following the invariable rule, the change $W_s \rightarrow W_p$ occurs with an absorption of heat. The volume change which accompanies this transformation is so slight that it is uncertain which form is the more dense.

The pseudo-wollastonite melts at 1512° to a comparatively thin liquid, which almost always crystallizes above 1200° on cooling down again. This explains why true wollastonite cannot generally be formed from a liquid of its own com-

* All the numbers in this table are 7 microvolts too high, on account of a slight, unavoidable leakage current through the insulation of the hot furnace. Hence the true melting point is 16053 microvolts, as given in the previous table.

CURVE II.—Melting of Pseudo-Wollastonite.
Melting Point, 1512°.
Rate of Heating, 2·7° per minute.



position. We have already shown that the liquid can be undercooled to a glass; it follows naturally that by a suitable disturbance a sufficiently undercooled melt should crystallize directly to wollastonite. In fact, we have in one or two instances thus obtained well developed rosettes which the microscope showed were optically negative, and in one case the whole charge excepting a few surface grains yielded wollastonite. That wollastonite rarely forms in this way is due, first, to the difficulty of undercooling the melt sufficiently, and second, to the release of the heat of fusion which tends to raise the temperature again beyond the inversion point.

The addition to calcium silicate of fluorides or borates in the proper proportion (to which some investigators have resorted), of course lowers the temperature of crystallization; and it is to this influence rather than to any mysterious "mineralizing" action that the synthesis of natural wollastonite is to be ascribed. It seems not impossible also that for a similar reason Gorgeu may have obtained it together with chlorosilicates, as he claims to have done, by the addition of calcium chloride. So in the glasses of commerce which contain much sodium silicate, a slow cooling sometimes gives rise to crystals of wollastonite below the inversion point.

Although the *temperature at which wollastonite may crystallize from a magma* is conditioned by the composition of the

latter, it may be worth while to call attention to the fact that the value of the *inversion temperature* as a point of reference in geology is not impaired by the varying complexity in the composition of the magma, inasmuch as this temperature has to do with an equilibrium between two solid states of calcium metasilicate, and has no relation to the solution out of which either form crystallizes. It will of course be slightly affected by pressure in the usual way, and also to some extent by the impurities which, in small quantity, are found in the natural mineral, provided these are really dissolved in it.

IMPORTANT PROPERTIES OF THE TWO FORMS OF CALCIUM METASILICATE.

Symmetry.	Inversion Point.	Melting Point.	Specific Gravity at 25° compared with water at 25°.		
			Cryst. from an undercooled melt.	Cryst. from $Ca(VO_3)_2$.	Molten.
Wollastonite { monoclinic optically negative	1180°	....	2·915	*a*. 2·914 *b*. 2·912	....
Pseudo-Wollastonite { probably monoclinic pseudo-hexagonal optically positive	"	1512°	....	....	2·912

Optical Study.

In the thin sections which were made from the various preparations of calcium metasilicate, both forms, wollastonite and pseudo-wollastonite, were recognized, and determined by their optical properties alone, their morphological features being too indefinite and inconstant to be of service. Fortunately several of the optical characteristics of the two minerals differ sufficiently to render the separation under the microscope relatively simple.

Textually the preparations show considerable variation, although in general the artificial wollastonite occurs in fibrous or long prismatic aggregates, while the pseudo-wollastonite is more coarsely crystalline and granular in appearance. Radial spherulites of wollastonite in which the crystals are elongated parallel to the axis of symmetry (*b*) were observed frequently, especially in the sections of wollastonite from crystallized glass.

In size the crystals range from the finest cryptocrystalline aggregates to individuals several millimeters in length. As

a rule the crystals formed out of a melt are larger than those produced by heating the silicate glass.

Wollastonite.—Under the microscope the artificial wollastonite resembles closely natural wollastonite and often presents its characteristic arrangement of divergent fibers. The colorless laths are usually transparent and show perfect cleavage cracks parallel to their long direction. Twinning after a face in the orthodiagonal zone was recognized on several of the crystals. Two of the crystals formed from the melt of calcium metasilicate and calcium vanadate were of sufficient size (·1 x ·2 x ·5^{mm}) to permit goniometric measurement of their faces.* Both crystals were elongated in the direction of the axis of symmetry (*b*) and showed evidences of cleavage after *u* (001) and *c* (100). On the first crystal, the forms *u* (001),† *v* (101), *t* ($\bar{1}$01), *a* ($\bar{1}$02) and *e* (110) were observed; on the second, which was less perfect, the forms *c* (100), *u* (001), *t* ($\bar{1}$01) and *a* ($\bar{1}$02) occurred, with two uncertain forms (302)? and (203)?. The forms (001) and ($\bar{1}$01) were the best developed and gave sharp reflexion signals. The faces of the other forms were smaller and less satisfactory in their measurement. The accordance of the observed interfacial angles with those of natural wollastonite, however, was sufficiently close to prove their identity. The following comparison of their polar angles shows differences which are not greater than had been anticipated from the inferior reflexion signals obtained.

			Artificial Wollastonite.		Natural Wollastonite.	
Letter	Symbol.	Miller.	ϕ	ρ	ϕ	ρ
u	0	001	90°00′	5°30′±5′	90°00′	5°30′
c	∞0	100	"	90 27	"	90 00
e	∞	110	43 10	89 58	43 39	90 00
v	+1	101	90 00	45 06	90 00	45 33
a	$-\frac{1}{2}$0	$\bar{1}$02	"	19 54	"	20 03
t	−1	$\bar{1}$01	"	39 29	"	39 35

The greatest and least refractive indices were determined by Schrœder van der Kolk's‡ method of refractive solutions to be about 1·621 and 1·636. Birefringence, about 0·015. Optic axial plane, perpendicular to the cleavage lines. Optical character of principal zone, both positive and negative. Optical character of mineral negative with optic axial angle in air, 2 E = 69°30′−70°00′, measured on several different prepara-

* Goldschmidt's two-circled goniometer with reduction attachment was used.

† The crystallographic orientation of Goldschmidt's "Winkeltabelle," Berlin, 1897, pp. 286–287, has been followed in the notation.

‡ Kurze Anleitung zur Mikroskopischen Krystallbestimmung, Wiesbaden, 1898.

tions after the Bertrand-Mallard method. In certain sections the optic axial angle appeared to be smaller than in others, a fact for which no explanation has been found. Optic axial dispersion $\rho > \nu$. All of the above properties agree well with those of natural wollastonite and substantiate the thermal and chemical evidence of Messrs. Allen and White.

Several of the preparations of wollastonite were cryptocrystalline and could be identified only by their low birefringence and fibrous spherulitic character.

Pseudo-wollastonite appears either in the form of small irregular grains often tabular in shape or in short prisms or fibers arranged in parallel or divergent groups. The grains are transparent and show occasionally well developed basal and imperfect prismatic cleavage lines. Limiting refractive indices, about 1·615 and 1·645, as measured by the method of refractive liquids. Birefringence about 0·025–0·035, considerably higher than in wollastonite. It is interesting to note in this connection how slightly the mean refractive index of wollastonite differs from that of pseudo-wollastonite. Accurate optical measurement would be required to ascertain satisfactorily which mineral has the higher average index of refraction. The same conditions prevail in their specific gravities, where the differences observed might well be ascribed to experimental error.

Optical character, positive, with very small optic axial angle $2E = 0° - 8°$. Plates cut parallel to the basal pinacoid show in convergent polarized light an interference cross which can often be seen to open slightly on turning the stage. The optic axial angle thereby is so small that from it alone the mineral might be regarded uniaxial, the mere opening of the interference cross being an optical anomaly analogous to the irregularities noted in many minerals. This is the view taken by J. H. L. Vogt* in his studies on the formation of minerals in slags. His opinion was strengthened by the hexagonal form of the crystals and by the observed extinction parallel to the basal pinacoidal cleavage cracks. Doelter†, who also made an extended microscopic study of this silicate, came to the conclusion that the mineral was either hexagonal or orthorhombic in crystal system, his observations agreeing otherwise with those of Vogt. Bourgeois,‡ on the other hand, pronounced the mineral monoclinic. His work was accomplished before that of Doelter and Vogt and appears to have been less extensive in scope. After a brief mention of the essential optical features he describes the occurrence of twinning lamellæ in certain of the

* Mineralbildung in Schmelzmassen, Kristiania, 1892, 57–59.
† N. Jahrb. f. Min. 1886, i, 119–122.
‡ Bull. Soc. Min., v, 14–15.

elongated crystals and interprets them as indicative of the monoclinic system. Doelter also mentions in passing the rare occurrence of twinning lamellæ in his preparations, but seems to have attached no significance to the fact. The present writer also observed in several of his sections sharp and occasionally polysynthetic, twinning lamellæ which were not unlike oligoclase feldspar twins in appearance. On a plate perpendicular to the optic normal the twinning lamellæ were normal to the plate and parallel to the basal pinacoid, their trace running parallel to the basal cleavage lines. The lamellæ showed an extinction angle $a : a = 2°$. Since the cleavage cracks are not perfect, the small extinction angle of 2° might easily be overlooked, under ordinary circumstances, and the extinction be considered parallel. In the hexagonal and orthorhombic crystal systems the basal pinacoid is a plane of symmetry and cannot act as a plane of twinning nor show an extinction angle, however small. The fact, then, that twinning after the basal pinacoid does occur in the pseudo-wollastonite crystals and does show an extinction angle, the double of which when taken between adjacent lamellæ is 4°, precludes the uniaxial and orthorhombic crystal systems. The writer considers the mineral with Bourgeois as probably monoclinic. The twinning law is analogous to that of Tschermak in the micas, where the basal pinacoid is also the plane of composition. Since its crystals frequently similate hexagonal forms, pseudo-wollastonite may well be treated as pseudo-hexagonal and probably monoclinic in form. It is not a modification of the natural monoclinic wollastonite. and differs from the latter profoundly in optical as well as crystallographical features.

Paramorphic changes.—The phenomenon of paramorphism, the change of crystal structure of a chemical substance in the solid state with consequent preservation of the crystal habit of the original form, is well illustrated in the inversion of wollastonite to pseudo-wollastonite. Since in certain paramorphic minerals it has been noted that a plane of symmetry or other direction may be common to both simulated and simulating mineral, several experiments were made to ascertain whether any crystallographic or other relations exist between the original wollastonite crystals and the pseudo-wollastonite which replaces them. Cleavage fragments of natural wollastonite from Diana, N. Y., were heated in an electric arc and then cooled rapidly by plunging them into mercury. Sections from this preparation showed that the wollastonite had thereby passed into the pseudo-form without any apparent regularity. The fibers of the original wollastonite were unaltered up to that portion which had touched the electric arc, from which point outwards irregular grains of pseudo-wollastonite occurred

without recognizable crystallographic grouping. The contact between the natural and pseudo form was sharp, indicating that the transition had taken place without any intermediate stage.

In a second experiment, natural wollastonite was heated in the electric furnace to 1260° and thus changed in the solid state to pseudo-wollastonite. The resulting mass consisted again of grains of the pseudo form, irregularly arranged, although indications of the original fibrous wollastonite texture are still indistinctly shown.

The conditions were altered in still another experiment by heating artificial wollastonite crystals, which had been obtained by crystallizing the silicate glass, to the inversion temperature (1190°) for about an hour. The resulting preparation was instructive in showing the paramorphic change in its incipient stage. The original larger crystals were filled with particles and clusters of the pseudo-form, arranged without apparent regard to the host. Had the preparation been allowed to remain at the inversion temperature for a longer period of time, the change would undoubtedly have progressed until all original wollastonite fragments had been completely replaced by innumerable pseudo-wollastonite grains.

As the above experiments were made with cleavage fragments of natural and artificial wollastonite which are not so well adapted to show paramorphism as crystals, artificial crystals of wollastonite obtained from the calcium vanadate flux were heated in the electric resistance furnace above the inversion temperature, and the product examined. The original crystals were elongated parallel to the axis of symmetry (b) and were bounded chiefly by forms of the orthodome zone with perhaps the unit prism and unit clinodome forms. After the alteration, each one of the original wollastonite crystals was found to have changed entirely to one pseudo-wollastonite individual alone, and rarely to two or more grains, as is usually the case, a remarkable fact which may be due perhaps to the minute size of the original crystals and to the equality of specific volumes of the two forms. In one instance a basal section of the pseudo-form was contained in the orthodiagonal zone of the original mineral, while in another plate cut perpendicular to the optic normal, sharp twinning lamellae were visible, the traces of which ran parallel to a unit prism or clinodome form terminating the crystal and making an angle of 29° with the direction of elongation of the simulated crystal. From these and other observations, it is evident that, generally speaking, in paramorphic change the planes of symmetry of the two forms do not coincide. Certain crystallographic directions,

however, may or may not retain their character during the change.

The paramorphic change of pseudo-wollastonite to wollastonite, which is the more imporant from the geologist's standpoint, could not be observed, since the conditions under which it was effected involved solution and precipitation, and did not occur in the solid state.

Summary.

The chief results attained by the optical study of the calcium metasilicate preparates were:

1. Identification of artificial wollastonite, whose properties agree precisely with those of natural wollastonite.

2. Determination of the pseudo-hexagonal, probably monoclinic, crystal system of the second form of $CaSiO_3$; in its crystals the occurrence of distinct and often repeated twinning lamellae parallel to the basal pinacoid and with an extinction angle a: $a = 2°$, was considered the decisive factor.

Geophysical Laboratory, U. S. Geological Survey.

Art. VII.—*Studies on Early Stages in Paleozoic Corals;** by C. E. Gordon.

The group of the Anthozoa has been the object of careful and detailed study for many years. The discovery that these organisms were really animals enlisted the attention of many investigators during the latter years of the eighteenth century. As first defined, the group included the Hydroid polyps, Bryozoa and Sponges; forms now known to be quite distinct. In 1828 Milne-Edwards showed that the "Sea-mat" and allied forms possessed a definite mouth and anus. Later the Sponges were made a distinct class, and finally the Hydroid types were firmly established as a distinct division of the Cœlenterates. "The anatomy and classification of the group thus purged of intruders were placed on a firm basis by the classical works of Dana and of Milne-Edwards and Haime (1857)." Since then studies in the development, comparative anatomy, and histology of the Anthozoa have contributed to a further and more exact knowledge of the group, although much remains that is yet doubtful and obscure. Especially is this true of the extinct Anthozoa of Paleozoic time: the Rugosa of Milne-Edwards and Haime, the Tetracoralla of Hæckel.

Since with these extinct forms only the hard parts are preserved, the study of relationships and mode of development is exceedingly difficult, and all conclusions on these points are necessarily, to a greater or less degree, matters of conjecture and inference. Several investigators, however, have endeavored to show the relationship of these extinct types to modern forms. How far they have succeeded in doing this is still a matter of dispute.

In so far as the plan of structure, which should be understood to mean the plan of growth from the earliest stages, can be proved to be similar to that of modern forms, just so far can relationships be assumed. Here we recognize that an inference can be drawn from a study of the hard parts, for example, the arrangement of the septa in corals. This arrangement is such that a reasonable assumption may be made as to their order of appearance. The difficulty must lie in securing specimens well adapted to show primitive characters with respect to the plan of growth of these septa.

With modern corals the order of appearance of the mesenteries is made of prime importance, and since the septa follow the mesenteries, the endeavor to classify the fossil forms has

* The studies embodied in this paper were carried on in the Paleontologic Laboratory of Columbia University, New York City.

been on the order of appearance of the septa, so far as could be inferred by a careful study of early stages. It is by no means true, however, that the early stages of all fossil forms will give us the clue to the phylogeny of the group. It frequently happens that certain individuals represent a specialized condition and are, on that account, not suitable for working out their own life history, which could be interpreted only by a careful comparative study of many individuals. This specialized condition may result from an acceleration in development of certain ancestral characters resulting in a premature appearance of certain stages which normally belong somewhat later in the animal's life, and which obscure the early conditions by their premature development; again, certain characters are retained longer than usual and are prolonged to the obliteration of later stages, for the appearance of which the life of the animal is not long enough. In interpreting the structural characteristics of any species the possibility of specialization must not be overlooked. Among forms somewhat removed in geological time from the ancestral stock, one must look for types in which acceleration, or retardation, or both, have been important factors in altering early ancestral conditions, and have produced new species, or varieties, according to one's choice of designation.

It is not within the province of man to say where, or in what parts, these modifications are to take place when only natural conditions operate to produce them. They are to be looked for anywhere, and it is reasonable perhaps to expect them in parts which have taken on new physiological importance, or have ceased to have such importance, as responses to certain conditions. Instances are numerous which forcibly illustrate the principles of acceleration and retardation. The genera Cyathophyllum and Heliophyllum are distinguished by the presence in the latter of carinae. But sections of certain Heliophyllums (*Heliophyllum halli*) show the carinae appearing very late in the life of the individual.* Up to the time of their appearance they are not to be distinguished from Cyathophyllum. In other individuals the carinae appear so early as entirely to obliterate the Cyathophyllum stage. It is clear that here are two types originating from a common ancestor, which had both a Cyathophyllum and a Heliophyllum stage, the latter being a late ephebic character. One retained the Heliophyllum stage as an ephebic character, and is to be regarded as a retarded type. The other became accelerated until the carinae stage became established as a nepionic character. It is apparent that here are two distinct types, each

* "Hamilton Group of Thedford, Ontario," Shimer and Grabau; Bull. Geol. Soc. Amer., vol. xiii, pp. 167–168.

having a Cyathophyllum ancestor, but that acceleration has produced in one case a distinct type in which the Cyathophyllum stage is either lost, or is of such short duration that it escapes notice.

In attempting to arrive at some definite conclusion as to the ancestral condition of any fossil group, or as to whether any particular plan of structure in fossil forms is a primitive one or not, one must not ignore these facts so obviously illustrated in many groups that have been carefully and successfully studied. In the absence of proof that the specimens in hand are primitive, or that they illustrate a primitive condition, of which one must always be in doubt, one must in order to meet the first requirements of a safe premise select a type most likely to be primitive, and this must be done on the basis of chronogenesis. A type occurring late in geological time, at least a considerable time subsequent to the earliest occurrence of a type at all similar, is likely to be far from primitive, in all respects at least, and at all events is not a safe type for study. But a specimen selected on the basis of its early appearance in geological time may be presumed to give the most primitive conditions which it is possible to obtain until an earlier form which is favorable for study can be secured.

Dr. J. E. Duerden has attempted to show by studies based on *Lophophyllum proliferum* that it is unnecessary to "account for a primitive tetramerism" in the Rugosa.* He would, on the basis of his studies, consider the quadripartite symmetry as a secondary development erected on a primitive hexameral arrangement of the primary septa; and by the development of the secondary septa, according to his interpretation of the primary condition, he finds the Rugosa, in so far as *L. proliferum* may be representative, most closely related to the modern Zoantheæ. In this paper I am not so much concerned with establishing the relationship of the Rugosa as with discussing the probable number of the primary septa in these forms. Certain studies which I have undertaken seem to indicate that there is still good ground for believing that the tetrameral plan is a primitive one.† Moreover, a careful study of the diagrams in Duerden's paper has raised the question if after all they may not illustrate a primitive tetrameral arrangement of the main septa.

It will be necessary in order to make as full a comment as seems desirable on Duerden's studies of Lophophyllum to reproduce a few of his figures.

*Johns Hopkins University Circular, January 1902; Annals and Magazine of Natural History, May 1902.

†For valuable suggestions and criticisms in carrying on these studies the writer is deeply indebted to Dr. Amadeus W. Grabau.

In figure 1 we have a

"transverse section, through the tip of the corallum. The dark median lines of only six primary septa are present, but the outlines of the septa as a whole are not clearly determinable, their surfaces being fused throughout. The two median septa are represented by a continuous line, while the other four septa are arranged as an upper bilateral pair and a lower bilateral pair. Of the six primary interseptal spaces the two upper are slightly smaller than the others. By interseptal spaces may be here understood the interval between the dark lines of two contiguous septa; the septa are so broad as to occupy the whole of the calicinal cavity, leaving no interseptal loculi."

FIGURE 1. *Lophophyllum proliferum.* Transverse section through the tip of the corallum. After Duerden.

The author explains that the terms "upper" and "lower" are used merely for convenience and have no morphological significance. I wish here to call attention to Duerden's observation that the two upper "primary" (of Duerden's figures) interseptal spaces are smaller than the others, as this fact lends some support to a different interpretation of the figures from that which Duerden had given and which I presently wish to discuss.

"In all the figures the upper border corresponds with the convex side of the coral, and the lower with the concave border; the primary septa are indicated by the Roman numeral I, and the later septa by the letters A-D, according to their order of appearance within the four primary interspaces."

The reader's attention is again called to the exact language of the author, as great stress is laid by him upon the development of these septa in four primary interseptal spaces, which according to him do not represent the whole number, but only four out of six such spaces. I think another interpretation may be given to this early arrangement as exhibited in the apical section studied by Duerden.

In figure 2, which is a transverse section through the tip of another corallum taken comparatively a little higher than in the case of figure 1, two new septa are making their appearance, apparently as a unilateral pair. This is probably to be explained as a case of slightly unequal growth, as Duerden remarks. The dark tadpole-shaped spaces represent the interseptal loculi and partly indicate the boundaries of the septa. The dotted line in all the figures marks the outline of the actual section.

Figure 3 represents a transverse section of a third corallum taken a little higher than in the previous sections. Duerden remarks that the six primary septa are recognizable by their greater size. The outlines of the septa are indicated in the figure by the thin marginal lines and the oval interseptal loculi. The two median septa are now distinct from one another and the upper is larger than the lower. Duerden indicates that the former is

"thereby already recognizable as the main or chief septum."

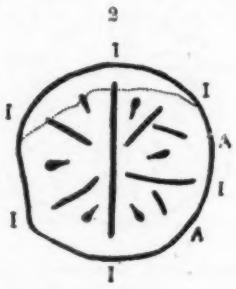


FIGURE 2. *L. proliferum.* Section through the tip of a second corallum; a little higher than in figure 1. After Duerden.

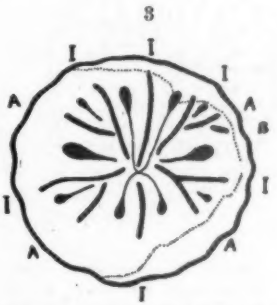


FIGURE 3. *L. proliferum.* Section of a third corallum from a still higher level. After Duerden.

He also makes the important observation that the

"upper primary interseptal spaces are much narrower than the middle and lower interspaces. Within each of the latter an additional septum (A) has appeared, and within the middle, right interspace the rudiment of a second additional septum (B) occurs. No new septa are ever developed within the two upper interseptal spaces."

Figures 4 and 5 are easily interpreted with respect to what has already been explained concerning the structural features of previous figures. Figures 6 and 7 will be referred to again.

The reader's attention is now directed to figures 8, 9, 10 and 11, which are Duerden's diagrams reproduced again, but this time inverted. This has been done for the sake of easier comparison. In figure 8 it will be noticed that what are now the upper lateral septa are, as indicated by the dark lines, more nearly at right angles with the median than are the lower ones, while the median dark lines of the lower ones in this figure (upper in Duerden's) have a proximity to the median dark line which is at this stage very noticeable and suggestive.

Before entering upon a further discussion of the diagrams obtained by inverting Duerden's figures, I wish to call atten-

tion to the possibility, which I have suggested above, of a specialized condition in *Lophophyllum proliferum*. Lophophyllum is a Carbonic type. It occurs comparatively late in the geological history of the Rugosa. It may, therefore—I should say rather, it must, therefore—have been somewhat

4

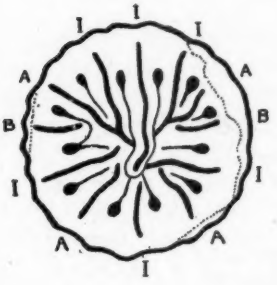


FIGURE 4. *L. proliferum*. Section from same specimen as in case of figure 3, but a little further from the apex. After Duerden.

5

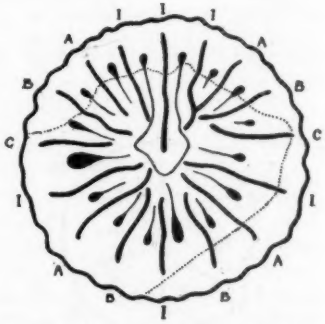


FIGURE 5. *L. proliferum*. Section of same corallum as before from about the middle of its length. After Duerden.

modified from an earlier condition. Whether this modification took place in the arrangement or order of appearance of the septa there is no absolute means of ascertaining, while one cannot gainsay the possibility that either acceleration, or retard-

6

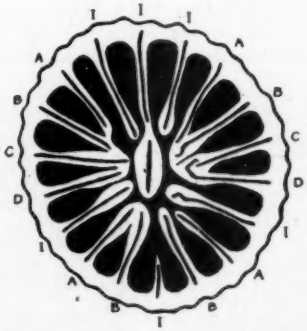


FIGURE 6. *L. proliferum*. Section from upper part of the same corallum as before. After Duerden.

7

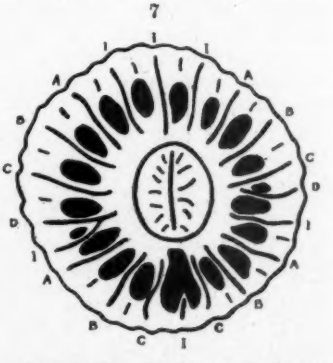
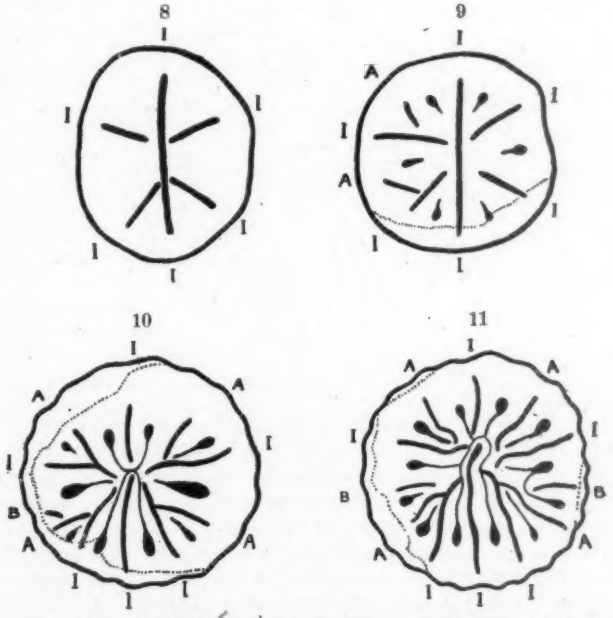


FIGURE 7. Section towards the upper region of a fourth individual. After Duerden.

ation, or both, have operated to produce an apparent anomaly in Lophophyllum in these respects.

The arrangement and order of appearance of the septa in the Zaphrentoid coral, as generally accepted, is illustrated in figure 15; (*h*) is the "cardinal" septum; (*g*) the "counter" septum; (*s*) the "alar" septa. The radiating lines indicate septal margins as they appear on the surface of the corallum when viewed from below. By the figure it will be seen that in the cardinal quadrant the septa first to appear take a position next the alar septa. In the counter quadrants the first to



FIGURES 8, 9, 10 and 11. Figures 1, 2, 3 and 4 of Duerden, inverted.

appear take a position next the counter septum. Let us carefully examine Duerden's figures to see if in any way they may reveal traces of a tetrameral arrangement of the septa according to the law apparent in the development of the septa in the Zaphrentoid coral as above explained.

By referring to figure 9, which it will be remembered is Duerden's diagram (figure 2) inverted, we observe the appearance of two secondary septa, each marked A, apparently as a unilateral pair. I have already remarked that this appearance as a unilateral pair may be explained on the principle of unequal growth. Since we are concerned only with their relation to the septa, marked in the figure by the Roman numeral

I, this unilateral order of appearance is of no significance, particularly as later figures almost conclusively show that it is simply a matter of unequal growth. It will be observed in figure 9 that the septum marked (A) bears a relation to the septum marked I in the lower left hand quadrant very similar to the relation which septum number 2 in the counter quad-

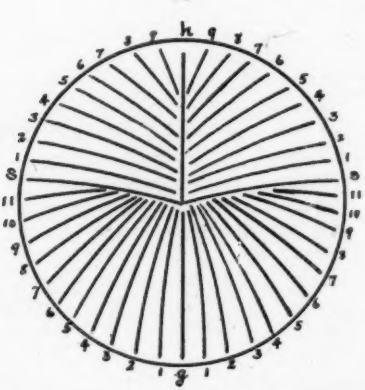


FIGURE 15. Plan of the septa in a Zaphrentoid coral.

rant of figure 15 bears to septum number 1. Likewise the septum marked (A) in the upper left hand quadrant of figure 9 holds a relation with reference to the adjacent primary septum similar to that which number 1 in the left hand cardinal quadrant of figure 15 bears to the adjacent transverse septum. It will be remembered, also, that in the above explanation of Duerden's figure 1, the comparative thinness of the upper pair of septa marked I was pointed out and that this was considered to be suggestive.

In figure 10 (figure 3 of Duerden, inverted) we observe a further increase in the number of secondary septa. Here the comparative thinness of the lower pair of septa marked I is again noticeable. In the upper quadrants are two secondary septa marked (A), each lying adjacent to the upper lateral "primary" septum on the side in which it appears. In the lower quadrants are two new septa marked (A) and in the left the beginning of a third, marked (B), which bears the relation to (A) that the latter holds with respect to the adjacent septum marked I. In this figure we also notice the division of the median septum into an upper and lower portion, the upper part of which, in Duerden's figures, is marked the "cardinal," the lower the "counter"; i. e., in Duerden's diagram 3, the upper

(the lower here) is called the "cardinal," and the lower (the upper in figure 10) is called the "counter." Figures 4 and 11 mark an increase in the number of secondary septa, and a noticeable increase in the length of the "cardinal" septum, and a shortening of the "counter" septum. In figure 11 it will be observed how similar the general arrangement of the septa is to that given in figure 15. The lower portion of the median corresponds to (*g*) in figure 15, the upper to (*h*). In the upper quadrants the secondary septa (A) in their relations to the upper pair marked I, follow the plan exhibited in the cardinal quadrants of figure 15. In the lower quadrants the secondary septa marked (A) and (B), as also do the "primary" septa (Duerden) marked I, have an arrangement that strongly suggests the condition in the counter quadrant of figure 15. Figures 5 and 12 show this arrangement even better, and bear a striking similarity to figure 15. There is now evident a striking bilateral arrangement of the septa, which according to Duerden and Pourtalès proceeds from an unsymmetrical development of the secondary septa in only four of six primary interspaces—proceeding as they do on the assumption that there are six primary septa.

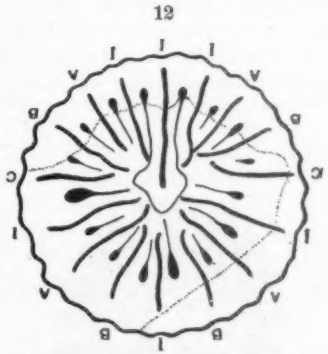


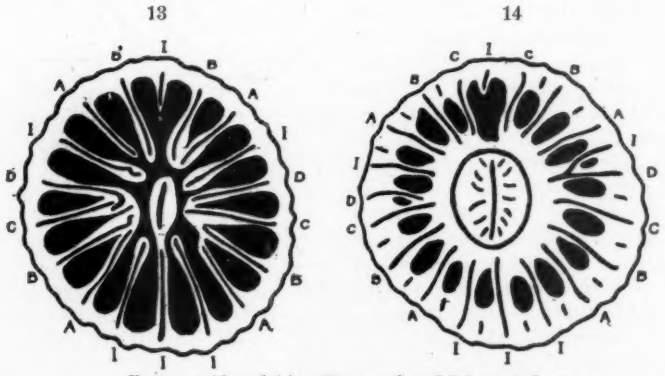
FIGURE 12. Figure 5 inverted.

An examination of figures 13 and 14 shows the position of the fossula in Lophophyllum to be in the same position as in the Zaphrentoid coral. To designate the cardinal septum always as the primary septum on the convex side of the corallum (after Nicholson) introduces some difficulty in making comparisons. The cardinal septum is to be regarded as that which, with the secondary septa in the same quadrant, exhibits a pinnate arrangement. That this may occur on the concave or convex side of the corallum is well known. According to Jakowlew the one fossula which can be determined is always developed on the cardinal septum.* Both the pinnate arrangement of the septa, which marks the position of the cardinal septum, and the fossula are by this author regarded as the product of the mode of growth of the corallum. However thatmay be, we have examples of the fossula and the cardinal

* "Ueber die Morphologie und Morphogenie der Rugosa," Verhandlungen der Russisch-Kaiserlichen Mineralogischen Gesellschaft zu St. Petersburg. Bd. XLI, Lief 2, 1904.

septum occurring on the concave side. Since we find not only the fossula, but also the pinnate arrangement of the septa, occupying the position of the lower portion of the median septum in Duerden's figures, this portion must be the cardinal, which in this specimen is on the concave side; and the upper portion is the counter instead of the cardinal, as Duerden has designated it. That this interpretation is correct is clearly shown by the figures. We have now simply to invert the diagrams to get a well organized Zaphrentoid type, in so far as the adult arrangement of septa and fossula are concerned.

It remains yet to consider the two upper "primary" septa of Duerden's figures in more careful detail. Certain studies



FIGURES 13 and 14. Figures 6 and 7 inverted.

which I have made on *Streptelasma profundum* from the Black River limestone seem to indicate most strongly a tetrameral plan of growth in the primary septa of the Rugosa; to use a borrowed phrase, "in so far as this type may be taken as representative." These studies will be given in greater detail presently. Their significance here, however, is to indicate that the tetrameral arrangement is not a secondary development on a hexameral basis, but on the contrary, that the hexameral arrangement in the tip of Lophophyllum is really only apparent and that *L. proliferum* from the beginning exhibits a quadripartite plan of the septa. To one who examines Duerden's figures the hexameral plan at first sight seems to be the only way of interpreting this very early condition. And I am well aware that by some it is likely to continue as the only interpretation.

Jakowlew came to the important conclusion that the primary spaces in which the secondary septa did not develop

appeared adjacent to the counter septum without regard to whether the latter appeared on the convex or concave side of the polyp.* In so far as Jakowlew's careful comparative studies are conclusive this would again indicate that what Duerden has designated as the cardinal septum is really the counter septum, as I, by comparison with a typical Zaphrentoid arrangement above, have pointed out to be the case.

By an examination of the diagram of the adult we are further impressed with the fact that the so-called primary spaces in which secondary septa do not develop are at the time of maturity not to be distinguished in any respect from the spaces which separate the secondary septa in the same quadrants. We note also that the lateral septa marked I in the upper quadrants of Duerden's figures have a position and an order of appearance which, if they were to be regarded as secondary septa, would correspond to the septa marked by the Arabic numeral 1 in the counter quadrants of figure 15, which illustrates the usually accepted order of appearance in the Zaphrentoid coral. We are furthermore impressed by the fact that the later sections of the corallum (figures 7 and 14) show the appearance of the tertiary septa, in the two *Kammern* next the "cardinal" (Duerden) at the top of figure 7, having precisely the same relations to adjacent septa as do the tertiary septa in all *secondäre Kammern*. The tertiary septa may have no sequence value, but the fact that they appear at all in the "primary" interspaces next the "cardinal" septum is suggestive that these spaces do not differ essentially from the secondary interspaces.

I am aware that in support of the interpretation which I shall presently present as an explanation of the presence of this pair of so-called primary septa next the "cardinal" septum, I have no absolute proof. I have called the reader's attention to the striking resemblance which Duerden's diagrams have to the usually accepted arrangement and order of appearance of the septa in the Zaphrentoid coral when the diagrams are inverted and their structural features interpreted in the terms of Zaphrentis. In Streptelasma (figure 16) it will be seen that the tertiary septa are present also in all interspaces. As to any sequence in their order of appearance, it was not possible to determine in the specimen, as their lower ends were very thin, and the extent to which they went down into the calyx could not be traced. The lines representing the tertiary septa in figure 16 do not indicate their indistinctness at their lower ends.

With regard to the "ultimate fate of the two bilateral pairs of primary septa" Duerden expresses himself as follows:

* Ueber die Morphologie und Morphogenie der Rugosa," Seite 412.

"One pair forms the 'alar' or lateral septa of the paleontologist, while the two moities of the remaining pair, recognized by Ludwig and Pourtalès, but not accepted by Kunth, are disposed one on each side of the axial septum on the convex side of the calice."

By the several figures reproduced here, e. g., figure 5 or figure 12, we observe how accurately this statement disposes of the septa, so far as their position is concerned, according to the Zaphrentoid plan. We see the "two moities" occupying exactly the position which the first two secondary septa to appear in the counter quadrant should occupy and we see them appearing before those of the cardinal quadrant as the greater number of septa in the counter quadrant of the adult

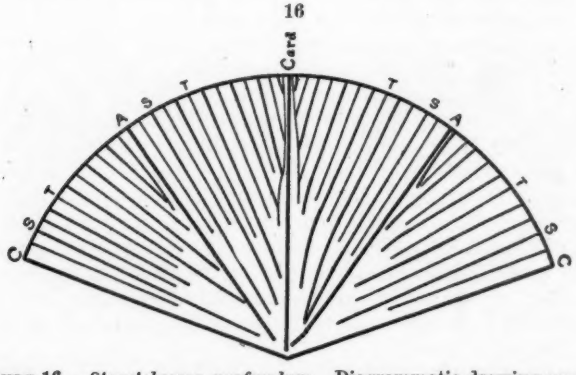


FIGURE 16.—*Streptelasma profundum*. Diagrammatic drawing somewhat enlarged.

would indicate to be the natural and logical order. The fact that the counter quadrant has the greater number of secondary septa supports the idea of acceleration in this quadrant. It is also to be noted that the number in the upper quadrant of Duerden's figures exceeds that in the lower quadrant by more than one, if we include the so-called "primary" septa.

How are we to account for this close resemblance of *L. proliferum* to a typical Zaphrentoid? Are we to regard these "primary" septa, which "are disposed one on each side of the axial septum on the convex side of the calice," as primary or secondary? If primary, what evidence is there that they are primary? If secondary, what evidence can be brought forward in support of their secondary nature, or what explanation can be offered of their appearance so early in the life history of the individual? The strongest evidence of their primary nature, of course, is their presence in the extreme tip of the

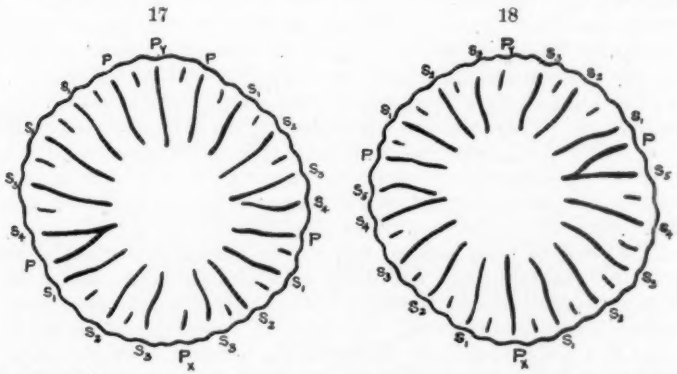
corallum. There they are, and if they do not show by their presence a primary hexameral arrangement some very strong evidence must be brought forward to show why they do not.

I am aware of the difficulty of explaining away their very apparent primary character, especially as any perfect series of fossil forms is not at hand to give us the absolute proof that *L. proliferum* may be at the extreme end of an accelerated series in which the pair of "primary" septa under discussion appear at progressively earlier and earlier stages in the life history of the individual until at last in *L. proliferum* we have them established so early that they simulate the nature of primary septa. In my criticism of Duerden's paper I wish to accord the author the credit due his careful investigations and to acknowledge his wide acquaintance with the Anthozoa. I would be understood in offering any other interpretation of his figures than that which he gives as being conservative, and far from committing myself as to having settled the matter. At the same time I believe that such an acceleration, difficult as it might be to account for, is far from being impossible, if it is not quite probable. In the absence of definite proof we have to rely upon analogy to a large extent, and call to our service in interpreting the structures in *L. proliferum* the knowledge furnished by studies upon other forms.

The idea of acceleration is by no means a new one. The principle undoubtedly has been an all important factor in bringing about those mutations which are the true species in certain evolutional series. In fact, it seems to be in many cases the only means of interpreting certain aberrant individuals which are so often grouped together in a heterogeneous way. We may be unable to explain why certain structures appear earlier in the life of certain individuals than they did in ancestral forms; but it is undoubtedly to be explained in many cases as a reaction towards its environment on the part of the individual, the response being a new anatomical structure, or a different plan of development because of a new importance of old structures, such as the assumption of a greater physiological importance of certain ones. On this wise it would not be difficult to imagine that for some reason or other, obscure as that may be, the mesenteries next the "cardinal" septum in Duerden's figures are really secondary septa called into being so early as to appear to be primary septa. The striking resemblance of Duerden's figures, if I may again call attention to this fact, to the usually accepted Zaphrentoid type of arrangement and the fact that the so-called primary septa follow the well recognized law of Kunth, are offered in

support of this interpretation; the possibility of acceleration makes the inference logical.*

If these two septa were called into being at a relatively early period, that is, before they normally would appear in a non-accelerated type, it is easy to conceive how, once established, this acceleration, as the name implies, would cause these septa to appear at an earlier and earlier stage until in a later geological type they would appear in the early nepionic stages so fully developed as to present the character of primary septa. Their true nature then, in the absence of a series showing this progressive acceleration, could be explained by noting the subsequent development of secondary septa that were not accelerated, and, in this connection, noting the final



FIGURES 17 and 18. A portion, in each case of figures 7 and 14, with new lettering.

position of the septa that were accelerated, as I have done. Duerden's figures, to my mind, lend themselves in every respect to this interpretation.

At the risk of repetition I have at this place introduced a portion, in each case, of figures 7 and 14 with new lettering, which may serve to recapitulate and make a little clearer the foregoing discussion.

Figure 17 shows in a diagrammatic way the value of the septa as interpreted by Duerden in figure 7. (P_y), "cardinal septum" (Duerden); (P_x) "counter septum" (Duerden); (P)

* The suggestion of Boveri that the anomalous number of the septa of the first cycle in *Tealia crassicornis* may be explained as due to the precocious development of four septa belonging to the second cycle, is a recognition of the fact that acceleration in development may operate to conceal a primitive condition. Boveri's suggestion is supported by his own observations on the peculiar mesenterial arrangement in an undetermined larval form. (This suggestion was not seen until this article was written.)

other "primary septa," (Duerden); (S) secondary septa. The subscripts indicate the order of appearance.

Figure 18 is a portion of figure 14 and is figure 17 inverted. The lettering in this case indicates the author's interpretation of the value of the septa. (P_y) "cardinal septum" (author); (P_x) "counter septum" (author); (P) "alar septa" (author); (S) secondary septa. The subscripts indicate the order of appearance. Note that the cardinal and counter septum are reversed and that the number of primary septa are reduced by two.

Duerden, from his wide acquaintance with modern corals, makes the statement that no living coral presents such a mesenterial (septal) sequence as *L. proliferum*, yet it bears the closest resemblance to what is found to be characteristic of Zoanthoid polyps, except that the mesenterial increase takes place in only two exocoelic chambers in these forms, while, as Duerden would have it, in *L. proliferum* it is carried on in four such chambers. Of whatever value the fact may be, it yet remains that no modern coral has precisely the same septal sequence as is described for *L. proliferum*, which suggests that here we have merely a specialized type of the Zaphrentoid coral. Starting with the hypothesis that the primary septal plan of *L. proliferum* is hexameral, we have yet to investigate other corals, selected with the purpose of getting a primitive species as well as one which is favorable for study, to find out how far they lend support to the hexameral primary septal plan or tend to disprove it.

The difficulty involved in getting sections of coral tips that really show anything one way or the other is appreciated only after one has made the attempt. The tips either break at an inopportune moment, or after sectioning show nothing conclusive. Turning from sections which revealed little or nothing, I was more fortunate in securing some specimens of *Streptelasma profundum* from the Black River limestone. The specimens were silicified and had been removed from their matrix by acid. Though small, they showed the well-preserved septa on the inside of the corallum. These specimens were carefully examined. Two were found which revealed the arrangement of the septa at the base of the calyx on the inside of the coral so satisfactorily that they were set aside for detailed study. During the attempt to sketch the relations of the septa in one of these specimens the corallum was unfortunately broken into several pieces so that it was impossible to make a satisfactory drawing. A drawing of the other is given in figure 16, which in all essentials is like the one which was broken.

The corallum of *Streptelasma profundum* in figure 16 is represented as split on the counter septum and rolled out; the point toward which the heaviest lines converge is the apex; the curved line is the circumference of the calyx; (C) is the counter septum; (S), the secondary septa; (T), the tertiary septa; (Card), the cardinal septum. The corallum was so small and fragile that it was impracticable to attempt drawing to an exact scale, as the measurements could not be made in the corallum without the risk of breaking it. Care was exercised not to exaggerate the relations of the septa, so that in the drawing, though necessarily more or less diagrammatic, one sees a very close approximation to the actual appearance. In this figure it is obviously impossible to represent anything but lengths. In doing this I have tried to be true to facts. At the base of the corallum (and in describing the corallum from now on it must be remembered that we are looking down into the vase of the corallum) the septa are not so deep (by depth I mean extension from the wall inward) as a little way up, as though they had undergone resorption or ceased to grow. In modern corals a resorption of the mesenteries takes place at the base, as the animal grows upward.* It is not unlikely that this is the explanation of the tapering off that was observable in all the septa which extended deepest into the calyx. Of the four primary septa represented in the drawing, the counter extended farthest down, the cardinal next, and the alar septa next. The bending represented in the alar septum on the right is meant to represent the slight deflection of the inner edge of the septum upward, as though the mesentery has been crowded by the counter septum at the base. Attention is directed to the fact that only four septa appear in the early stage of the corallum. The alar septum on the left is appreciably longer than the secondary septum adjacent to the counter represented in the left hand portion of the figure by S. The latter showed greater depth near the base than the corresponding one on the right, as though it had been resorbed to a less extent, or as though it had grown faster. The second secondary septum in the left hand counter quadrant exhibits a condition of unequal growth. The order of development of the secondary septa is plainly seen to correspond exactly to that in the Zaphrentoid coral in figure 15. With respect to the tertiary septa, although examined with the aid of a powerful binocular in artificial light, it was impossible in all cases to tell to what length they extended down into the coral. In the cardinal quadrants near the main septum they merged with a ridge

* "Morphology of Coral Polyps," J. E. Duerden, Smithsonian Miscellaneous Collection, Quart. Issue, vol. ii, No. 1, 1904, p. 98.

represented by the curved line, which ridge was small and of about the same size as the tertiary septa.

As was stated above, the specimen was examined by the aid of a binocular in electric light. No doubt was left in my mind that the four septa indicated by the heaviest lines in the figure extended farthest down into the base of the calyx. Not content, however, with my observations, I submitted the specimen to two others, whose results tallied with mine. The results, therefore, seemed to indicate that *Streptelasma profundum* showed a primary tetrameral arrangement and that the further addition of the secondary septa proceeded in accordance with the law that the Zaphrentoid type has been shown to illustrate.

In the criticism offered above of Duerden's figures I have, I think, offered another possible interpretation of the occurrence of one of the pairs of so-called primary septa in the tip of *Lophophyllum proliferum*. Whether this interpretation is accepted or not, I think it is by no means established that the hexameral arrangement is a primitive one. In the first place, as I have pointed out above, *L. proliferum* is in some respects, notably because of its occurrence in Carbonic time, not a suitable specimen upon which to establish a primitive arrangement of the septa. *S. profundum* from the Ordovicic was selected for study mainly because of its early geological occurrence. The fact that it shows a primary tetrameral arrangement suggests that such was the primitive condition. To my mind it suggests this because it is a comparatively old type and, because, so far as the septal sequence is concerned, it shows absence of acceleration.

It is evident, I think, that the primitive condition of these septa in the Rugosa is not yet settled. The tetrameral arrangement, if primary, will so long as this is made the basis of classification, place those corals which possess it in a group by themselves. No modern corals exhibit the peculiar septal plan as revealed in *Streptelasma profundum;* nor, in fact, as revealed in *Lophophyllum proliferum*. The fact that Lophophyllum is quite distinct from anything that is modern perhaps gives some support to the view that it is merely an accelerated type of a Zaphrentoid coral, occurring as it does among an extinct group.

Whether the hexameral plan is derived from a tetrameral one is still an unsolved mystery. Developmental studies among modern forms may yet throw some light on this question.

From the wide prevalence of the tetrameral arrangement among the extinct Rugosa it is probable that it is something inherent rather than acquired by mode of growth, especially

as it is characteristic not only of bent forms but also of simple, straight cones. At all events, one may take exception to the statement that "studies on the septal development of extinct Paleozoic corals reveal that in these early forms the primary septal plan was hexameral like that of modern forms."

Further studies upon well-preserved specimens of early Rugosa are much to be desired.

Postscript.

Since writing this article I have received and carefully read an excellent paper by Dr. Duerden on "The Fossula in Rugose Corals." In this article I find a full recognition of the principle of retardation in development. The author shows beyond question that the alar fossulae and the cardinal groups of shortened fused septa in Hadrophyllum are developmental stages when compared with the ephebic condition of a form like Streptelasma. Since retardation in development means the retention in the adult stage of characters which belong to earlier stages, nepionic or neanic, Hadrophyllum must be a retarded type when compared with a form like Streptelasma, which passes through a Hadrophyllum stage. Both forms are probably to be regarded as derived from a protostreptelasmic stock.

The author of the paper makes the point that,

"Whenever alar fossulæ are present they represent an incompletion in the establishment of the newer septa of the alar region as compared with species in which no alar fossulæ are represented; they have only a developmental significance and would not correspond with any structural peculiarity of the fully developed polyp."*

This is the point which I have insisted upon with reference to the pair of so-called "primary septa" in *L. proliferum*; namely, that they do not have the structural importance which Duerden gives to them, but that they have a developmental significance only.

Duerden further remarks:

"As would naturally be expected from such an explanation even individuals of the same species may vary much with regard to the presence or absence of alar fossulæ." †

This is evidently true. The only exception one might take to such a statement is the propriety of calling the variations

* "The Morphology of the Madreporaria, VI, The Fossula in Rugose Corals," p. 33.

† Ibid., p. 33.

members of the same species. For example, Hadrophyllums in which no alar fossulæ were present in the adult stage would be accelerated types and properly should be made a distinct genus.

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Art. VIII.—*The Behavior of Ferric Chloride in the Zinc Reductor;* by D. L. Randall.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cxliv.]

The column of amalgamated zinc as applied in the earlier form of the Jones reductor* or the simpler form now generally employed† has proved very effective in the reduction of ferric sulphate preparatory to the estimation of the ferrous salt by potassium permanganate. The impression has prevailed, however, that the salt of iron acted upon by the amalgamated zinc must be the sulphate and that chlorides and nitrates must not be present even in small amounts.

The following work was undertaken to see whether ferric chloride might not be treated effectively in the reductor and the reduced solution successfully titrated with standard permanganate. For this work a solution of ferric chloride was made up and standardized by evaporating known amounts with 10^{cm^3} of sulphuric acid to the fuming point of the acid, passing the solution thus freed from chlorides through the reductor, and titrating with standardized permanganate. In general the procedure was to first run 100^{cm^3} of warm dilute 2·5 per cent sulphuric acid through the reductor, next to pass in the iron solution diluted with 100^{cm^3} of the warm 2·5 per cent acid and then to wash down with 200^{cm^3} of the warm dilute acid followed by 100^{cm^3} of hot water. The receiving flask of the reductor was kept in a vessel containing running tap water, so that the solution was cooled as fast as it was reduced; and in some of the early experiments carbon dioxide was passed in at the beginning of the reduction to drive out the air and at the end of the reduction before titration, a practice which was found to be unnecessary and so was discontinued. In this work a column of amalgamated 20-mesh zinc was used in the reductor.

In the preliminary experiments there was some evidence in the high results that chlorine was evolved, even in dilute solutions, but this tendency was overcome by adding 1 gram of manganous sulphate in solution to the receiving flask before starting the reduction, according to the suggestion of Keissler‡ and Zimmermann§ to apply to titrations of ferrous salts by permanganate in the presence of chlorides.

Table I shows the results obtained under the varying conditions detailed.

* The Chemical Analysis of Iron, Blair, 2d edition, p. 203.
† Ibid., 4th edition, p. 94.
‡ Ann. Phys., cxviii, 41; cxix, 225–226.
§ Ber. Dtsch. Chem. Ges., xiv, p. 779.

TABLE I.

Exp.	$FeCl_3$ taken. cm^3.	Fe. grm.	H_2SO_4 2·5 %. cm^3.	HCl. cm^3.	Volume at titration. cm^3.	$MnSO_4$. grm.	$KMnO_4$. cm^3.	Fe found. grms.	Error. grms.
1*	20	·0349	100	0	600	0	19·50	·0354	+·0005
2*	20	·0349	100	0	600	0	19·53	·0354	+·0005
3*	20	·0349	100	0	600	0	19·45	·0353	+·0004
4*	20	·0349	100	0	600	0	19·49	·0354	+·0005
5*	20	·0349	100	0	600	1·00	19·30	·0350	+·0001
6*	20	·0349	100	0	600	1·00	19·30	·0350	+·0001
7*	20	·0349	100	0	600	1·00	19·20	·0348	—·0001
8*	20	·0349	100	0	600	1·25	19·28	·9349	±·0000
9	20	·0349	100	0	600	1·25	19·35	·0351	+·0002
10	20	·0349	100	0	600	1·25	19·20	·0348	—·0001
11	20	·0349	100	0	600	1·25	19·30	·0350	+·0001
12	20	·0349	100	0	600	1·25	19·21	·0348	—·0001
13	20	·0349	100	5	600	1·25	19·29	·0350	+·0001
14	20	·0349	100	10	600	1·25	19·30	·0350	+·0001
15	20	·0349	100	20	600	1·25	19·50	·0354	+·0005
16	20	·0349	100	20	600	1·25	19·50	·0354	+·0005
17	20	·0349	100	15	600	1·25	19·22	·0348	—·0001
18	20	·0349	100	20	1000	2·50	19·32	·0350	+·0001
19	20	·0349	100	20	1000	2·50	19·30	·0350	+·0001
20	20	·0349	100	30	1000	2·50	19·31	·0350	+·0001
21	20	·0349	100	30	1000	2·50	19·37	·0351	+·0002
22	20	·0349	100	35	1000	2·50	19·45	·0353	+·0003
23	20	·0349	100	40	1000	2·50	19·50	·0354	+·0005
24	20	·0349	100	50	1000	2·50	19·50	·0354	+·0005

In the last seven experiments by diluting abundantly it was possible to work with a greater amount of free acid. Having found the work to go successfully with small amounts of iron and dilute permanganate solutions the experiment was continued with the use of more ferric chloride and a stronger permanganate solution.

TABLE II.

Exp.	$FeCl_3$. cm^3.	Fe taken. grms.	H_2SO_4 2·5 %. cm^3.	HCl. cm^3.	Volume at titration. cm^3.	$MnSO_4$. grms.	$KMnO_4$. cm^3.	Fe found. grms.	Error. grms.
1	25	·0437	100	0	600	1·	7·70	·0434	—·0003
2	25	·0437	100	0	600	1·	7·73	·0435	—·0002
3	25	·0437	100	0	600	1·	7·76	·0438	+·0001
4	25	·0437	100	0	600	1·	7·74	·0436	—·0001
5	25	·0437	100	0	600	1·	7·75	·0437	±·0000
6	50	·0874	100	0	600	1·	15·50	·0874	±·0000
7	50	·0874	100	0	600	1·	15·49	·0873	—·0001

* CO_2 was used in receiving flask.

TABLE II (continued).

Exp.	$FeCl_3$. cm^3.	Fe taken. grms.	H_2SO_4 2·5%. cm^3.	HCl. cm^3.	Volume at titration. cm^3.	$MnSO_4$. grms.	$KMnO_4$. cm^3.	Fe found. grms.	Error. grms.
8	100	·1748	100	0	600	1·	30·90	·1742	—·0006
9	100	·1748	100	0	600	1·	30·92	·1743	—·0005
10*	50	·2532	100	0	600	1·	44·95	·2533	+·0001
11	50	·2532	100	0	600	1·	45·00	·2536	+·0004
12	50	·2532	100	0	600	1·	45·01	·2537	+·0005
13	50	·2532	100	0	600	1·	44·95	·2533	+·0001
14	50	·2532	100	0	600	1·	44·97	·2534	+·0002
15	100	·5064	250	0	800	1·	89·94	·5069	+·0005
16	100	·5064	250	0	800	1·	89·94	·5069	+·0005
17*	75	·4872	100	0	750	1·	70·81	·4871	—·0001
18	75	·4872	100	0	750	1·	70·75	·4867	—·0005
19	75	·4872	100	0	750	1·	70·83	·4873	+·0001
20	75	·4872	100	0	750	1·	70·82	·4872	±·0000
21	75	·4872	100	0	750	1·	70·83	·4873	+·0001
22	100	·6497	100	0	750	1·	94·43	·6497	±·0000
23	100	·6497	100	0	750	1·	94·44	·6498	+·0001
24	100	·6497	100	10	750	1·	94·44	·6498	+·0001
25	100	·6497	100	20	1000	5·	94·53	·6503	+·0006
26	100	·6497	100	25	1000	5·	94·53	·6503	+·0006
27	100	·6497	100	25	1000	1·25	94·53	·6503	+·0006
28	100	·6497	100	25	1000	1·25	94·48	·6500	+·0003
29	100	·6497	100	25	1000	5·00	94·49	·6501	+·0004

For purposes of comparison Table III gives some results obtained by the direct evaporation of the ferric chloride solution with sulphuric acid.

TABLE III.

$FeCl_3$ = cm^3.	Fe taken. grms.	H_2SO_4 1 : 1. cm^3.	Volume at titration. cm^3.	$KMnO_4$. cm^3.	Fe found. grms.	Error. grms.
75	·4872	25	750	70·75	·4867	—·0005
75	·4872	25	750	70·83	·4873	+·0001
75	·4872	25	750	70·83	·4873	+·0001
75	·4872	25	750	70·88	·4876	+·0004

These experiments show that it is possible to reduce ferric chloride in the zinc reductor and to determine the iron with success by potassium permanganate, provided the titration is carried on in the presence of manganous sulphate and in solutions sufficiently dilute. A small excess of hydrochloric acid has no influence on the result in dilute solutions, and by diluting to one liter the excess may amount to as much as 25^{cm^3} of the strongest acid.

In closing the writer expresses his thanks to Prof. F. A. Gooch for advice and assistance given during the progress of the work.

*Changed standard of solutions.

Art. IX.—*Dipnoan Affinities of Arthrodires;* by C. R. Eastman.

In the modern fauna, *Neoceratodus* stands out as an isolated landmark which has preserved faithful indications of the course evolution has taken amongst Dipnoan fishes. Compared with its nearest surviving relatives, *Protopterus* and *Lepidosiren*, it represents a relatively early larval stage of development; and its generalized organization bears witness to an extremely ancient origin. Regarding the Ceratodont type as decidedly more primitive in structure than that of *Dipterus* and its allies, and this view is supported by weighty evidence, two conclusions are possible with respect to their genetic relations. Either the more primitive type was in existence as early as the Devonian, and has survived practically unchanged ever since; or else modern Lung-fishes are to be looked upon as degenerate descendants of the *Dipterus* stock.

Objections stand in the way of either theory. Opposed to the first is the failure of Palæontology to realize our conception of a '*Palæoceratodus*'—that is to say, of fossil organisms standing in ancestral relations to both Ctenodipterines and Ceratodonts; and added to this is the difficulty of supposing any primitive type to have come down to us from remote ages without undergoing extensive modifications. The newer interpretation, proposed some years ago by Dollo,* is attended with still graver difficulties. For if we make *Dipterus* the initial term of a series leading through various Palæozoic genera and culminating in modern Lung-fishes, it will be necessary, as Professor Bridge has observed,† "to assume the possibility of an ossified skull so far degenerating as to lose almost all trace of endochondrial ossification, and secondarily revert to the condition of a skull so completely cartilaginous, and so primitive in other respects, as that exhibited by the living *Ceratodus*. So far as I am aware, there is no evidence to justify belief in such a possibility."

Comparison of other structural features besides the skull leads to altogether similar conclusions. Thus, the argument that the heterocercal tail of *Dipterus* must be antecedent to the diphycercal (or gephyrocercal) of *Neoceratodus* is met by Fürbringer‡ in following wise: "Nachdem in jeder Beziehung

* Dollo, L., Sur la phylogénie des Dipneustes, Bull. Soc. Belge Géol., vol. ix (1895), pp. 79–128.

† Bridge, T. W., Morphology of the Skull in Lepidosiren, etc., Trans. Zool. London, vol. xiv (1898), p. 370.

‡ Fürbringer, K., Beiträge zur Morphologie des Skeletes der Dipnoer. (Semon's Zool. Forschungsreisen in Australien, etc.), Jena Denkschr., vol. iv (1904), p. 500.

Ceratodus als der primitivere erkannt ist, muss auch die Annahme Dollo's, dass die Heterocerkie bei *Dipterus* etwas Primitives bedeute, fallen. Der Schwanz von *Ceratodus* zeigt zwar gewisse Rückbildungen; fur eine ehemahlige Heterocerkie bei ihm ist aber kein Beweis erbracht. Ich kann nach alledem, falls überhaupt eine Verwandtschaft zwischen *Dipterus* und den recenten Dipnoern besteht, diese im Gegensatz zu Dollo nur im Sinne von Woodward und Bridge auffassen."

Elsewhere the same author expresses himself unreservedly as to the relative specialization of the two types: "So wäre eines doch sicher, dass *Ctenodus* und namentlich *Dipterus* weit höher differenzirt sind als Ceratodus." Smith Woodward's opinion is that *Dipterus* and its allies are more specialized than any existing Dipnoan, and that the more generalized types have alone survived to represent the group at the present day.* Though he does not distinctly say so, his remarks would imply that the archetype of *Ceratodus* was ancestral to Ctenodipterines, the latter becoming finally extinct.

So much for a statement of the problem. Remains to inquire whether Palæontology can point the way toward a solution, even if indirectly. It has been said that no generalized form standing in the relation of ancestor to both *Dipterus* and Ceratodonts—the latter alone having persisted,—is known from the Devonian. Were such a form to be brought to light, or should its existence become a necessary postulate from other facts, it is evident that the question as to descent of modern Dipnoans would be stripped of much perplexity. In that event, also, there would be no necessity for an appeal to the imperfection of the palæontological record, such as has heretofore existed.

Now we confidently believe that the relations between recent and fossil Dipnoans will appear in much clearer light through comparison of *Neoceratodus* with Arthrodires, taking *Mylostoma* and *Dinichthys* as typical examples of the latter. There is no novelty in the idea that Arthrodires are related to *Dipneusti*, Newberry's original suggestion to that effect having found several warm supporters, notably Cope and Smith Woodward. It must be said, however, that the question has remained eminently controversial, first one and then another of rival interpretations gaining headway. That a singular lack of unanimity prevails as to the sytematic position of Arthrodires must be apparent to anyone having a casual acquaintance with the literature. The reason for such diversity of opinion evidently lies in non-recognition of homologies between the structural type of Arthrodires on the one hand, and those of fossil and

* Woodward, A. S., Catalogue Fossil Fishes British Museum, Part II (1891), introduc. p. xx.

recent Dipnoans on the other. It is even denied by writers of authority that such homologies exist. Dean, for instance, affirms that there is as much propriety in referring Arthrodires to the sharks as to Dipnoans, and in his latest contribution proposes to exclude them from fishes altogether.* Their nature is conceded to be highly problematical by President Jordan, who dismisses all thought of a connection between them and Lung-fishes. Thus, in the recent standard treatise of this author we read as follows: †

> These monstrous creatures have been considered by Woodward and others as mailed Dipnoans, but their singular jaws are quite unlike those of the *Dipneusti*, and very remote from any structures seen in the ordinary fish. The turtle-like mandibles seem to be formed of dermal elements, in which there lies little homology to the jaws of a fish and not much more with the jaws of Dipnoan or shark.
>
> The relations with the Ostracophores are certainly remote, though nothing else seems to be any nearer. They have no affinity with the true Ganoids, to which vaguely limited group many writers have attached them. Nor is there any sure foundation to the view adopted by Woodward, that they are to be considered as armored offshoots of the Dipnoans.

Again, at page 445 of the same work, occurs this passage:

> These creatures have been often called ganoids, but with the true ganoids like the garpike they have seemingly nothing in common. They are also different from the Ostracophores. To regard them with Woodward as derived from ancestral Dipnoans is to give a possible guess as to their origin, and a very unsatisfactory guess at that.

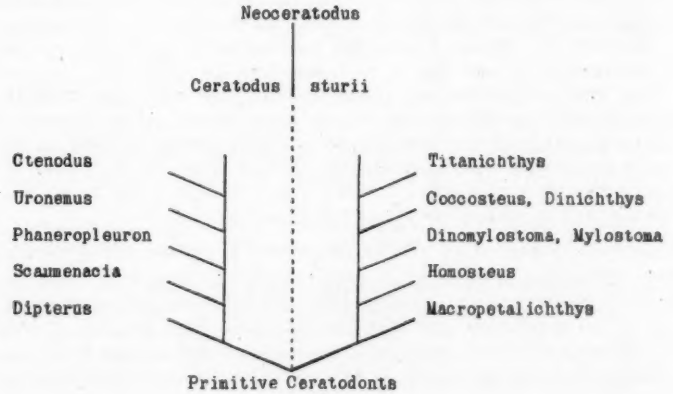
What is meant by the charge that Woodward's view rests upon insecure foundation is simply this: Arthrodires are provisionally classed amongst Dipnoans by Woodward on the assumption that they were autostylic; however probable the assumption, its truth remains to be demonstrated. And we must admit that, according to the usual interpretation of jaw-parts in Arthrodires, it would be very difficult to prove that autostyly existed. Granting all this, yet in the light of a novel interpretation, and of cumulative evidence drawn from various parts of the skeleton, the problem may be simplified, perhaps even placed in fair way of solution.

Our object will now be to suggest a new interpretation of the dental elements of Arthrodires, and to point out certain homo-

* Dean, B., Palæontological Notes, Mem. New York Acad. Sci., vol. ii (1901), p. 111.

† Jordan, D. S., Guide to the Study of Fishes, vol. i, p. 582 (New York, 1905).

logies between them and *Neoceratodus*. Provided a case be made out, the structural resemblances between the two types can hardly be explained except on the hypothesis of a common origin. It therefore becomes necessary to suppose that a generalized archetype of modern Dipnoans, probably derived directly from the Elasmobranch stem, was present during the lowermost Devonian, giving rise to two specialized groups, but manifesting itself, like *Limulus*, *Cestracion*, Scorpions and other archaic survivals, extraordinary persistence and conservatism ever since. The relations between the three recognized orders of Dipnoans would then appear after some such scheme as this:



In what follows we shall endeavor to show (1), that the dentition of Arthrodires is distinctly of the Dipnoan type, arising in the same manner and representing the same elements; (2) the relations of the Meckelian cartilage are identical in both types; (3) the dermal plates forming the cranial roof have undergone corresponding reduction and are arranged after essentially the same pattern, both in Arthrodires and Ceratodonts; and (4), *Neoceratodus* recalls throughout its entire organization, save for the absence of dermal armoring, the principal features of Arthrodires. Such intimate structural resemblances cannot be explained by parallelism, but point plainly to common descent.

Dentition of Dinichthys and Neoceratodus compared.—So long ago as 1875, Newberry* was struck with the close parallelism between the jaws of *Dinichthys* and those of *Pro-*

*Newberry, J. S., Rept. Geol. Surv. Ohio, Palæont. vol. ii (1875), p. 15.

topterus, even imagining the latter to be a lineal descendant of "Placoderms." Now the trenchant dental plates of *Protopterus* and *Lepidosiren* are clearly but a variant of the Ceratodont type, and we have to take only a step further to see that the Dinichthyid dentition has been similarly derived. No difficulty is offered by the so-called "premaxillary" teeth of *Dinichthys*, which are the precise equivalents of the vomerine pair in modern Dipnoans. As for the characteristic crushing plates in upper and lower jaws of Ceratodonts, these occur normally in *Mylostoma*, but in *Dinichthys* have become rotated so as to stand upright in the jaws, their outer denticulated margins functioning against one another like the blades of a pair of shears. An inkling as to how this variation was brought about is afforded by the Triassic *Ceratodus sturii*,* which may be taken to represent an incipient stage of metamorphosis. The dental plates of this form are seen to be turned more or less on edge, the corrugations interlocking in opposite jaws when the mouth is closed, and a rudimentary beak being developed in front which recalls the well-known projection in Dinichthyid mandibles.

As for the so-called "maxillary" or "shear-tooth" of *Dinichthys*, this corresponds plainly to the triturating upper (palato-pterygoid) dental plate of Ceratodonts, turned rather more upright than in *C. sturii:* and its anterior process or "shoulder" is represented by the forwardly placed ascending process of modern forms.† In Arthrodires, as in other Dipnoans and higher forms, the functional lower jaw is formed by membrane plates which have ossified around the Meckelian cartilage. Distinct angular and articular elements appear to be wanting in *Dinichthys*, but the splenial is strongly developed, supporting the dental plate properly speaking in front, and being articulated posteriorly with the cranium by cartilage, as in *Neoceratodus*. But one interpretation can be given of the conspicuous groove which extends forward along the inferior border of the splenial, passing underneath and to the inner side of the dental plate proper, and terminating at the symphysis. In it were lodged remnants of the Meckelian cartilage, precisely as in the living *Protopterus*.‡ Intermandibular teeth have not been definitely proved to occur, although their presence would be in strict accord with embryological evidence, and the appearance of certain specimens has created a

*Teller, F., Ueber den Schädel eines fossilen Dipnoërs, Abhandl. k. k. Reichsanstalt Wien, vol. xv (1891), pt. 3, pl. iv.

†This process is well shown in Plate 1*a*, fig. 4, of Miall's "Monograph of the Sirenoid and Crossopterygian Ganoids." Palæont. Soc., 1878.

‡Wiedersheim, R., Morpholog. Studien, Heft 1, p. 55, pl. ii, figs. 3, 8. Fürbringer, K., *op. cit.*, p. 481, pl. xxxix, fig. 28.

surmise that such were developed;* moreover, in *Coccosteus* we are confronted with a denticulated symphysial margin the significance of which has not been explained. Finally, it should be noted that an approach to the Dinichthyid form of mandible is made even amongst Ctenodipterines,† and some of these also developed cutting surfaces, as in *Sagenodus pertenuis*, for instance.

Dentition of Mylostoma and Neoceratodus compared.—Our knowledge of *Mylostoma* received important additions a few years ago, as the result of Dr. Bashford Dean's investigation of the type species, *M. variabile*.‡ In the light, however, of

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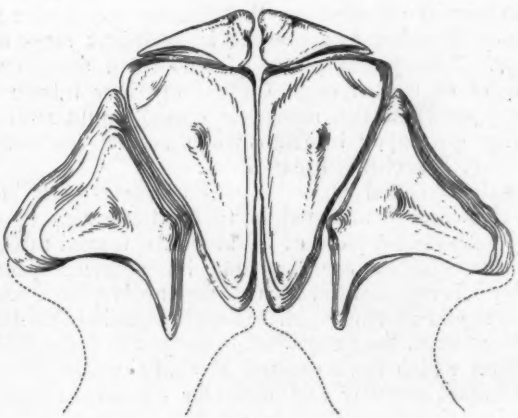

Fig. 1.—Upper dentition of *Mylostoma variabile* Newb., from the Cleveland shale of Sheffield, Ohio. x ½.

freshly discovered material, it is clear that this author was not entirely successful in determining the relations of the palatopterygoid plates in the unique specimen studied by him. That their true arrangement is depicted in the accompanying text-figure 1, can be proved in several ways, as follows: First, in no other position is there such accurate fit between upper and lower dental plates when the jaws are closed. Secondly, this reconstruction is in harmony with embryological evidence. And thirdly, it is identical with the arrangement recently

* Dean, B., Fishes, Living and Fossil, p. 133. (New York, 1895.)

† Atthey, T., On Ctenodus obliquus, etc., Ann. Mag. Nat. Hist. ser. 4, vol. xv (1875), p. 309, pl. xix, fig. 2. By Smith Woodward this species is considered identical with *Sagenodus inæqualis* Owen.

‡ Dean, B., Palæontological Notes: On the Characters of *Mylostoma* Newberry, Mem. N. Y. Acad. Sci., vol. ii (1901), pp. 101–109.

worked out for a new genus, intermediate between *Mylostoma* and *Dinichthys*—as the name *Dinomylostoma* implies—from the Portage beds of Mt. Morris, New York. For the privilege of studying the important specimen referred to, the writer is indebted to his friend Professor Schuchert, of Yale, in whose custody it is, and at whose suggestion the specific title is inscribed to the memory of the late Professor Beecher.

It is beside our purpose to present here a detailed account of the new form; suffice it to note that it permits accurate

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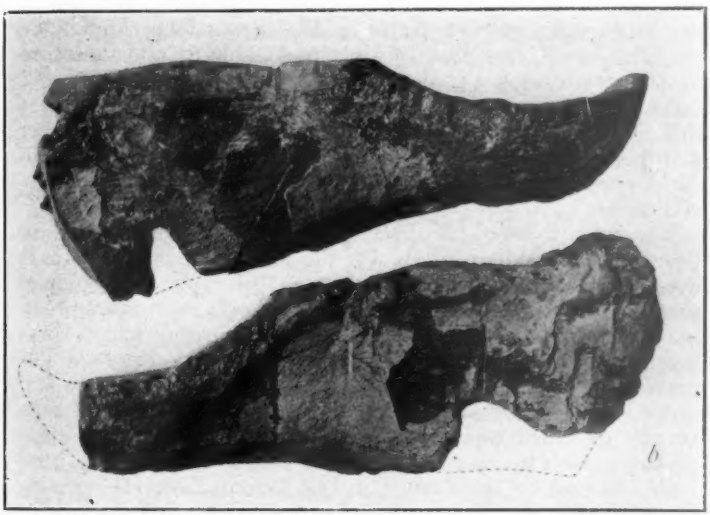

Fig. 2.—External aspect of (*a*) right, and (*b*) left mandibles of *Dinomylostoma beecheri* (MS.), from the Portage of western New York. x ½.

reconstruction of the entire dental apparatus, and acquaints us for the first time with the articular union between the lower jaw and cranium of Arthrodires. In this latter respect the conditions are exactly as we should anticipate from analogy with *Neoceratodus;* the articular cartilage is attached to the outer surface of the splenial at its posterior extremity, and forms a hinge with the suspensorial cartilage of the cranium. Whether this latter was in direct connection with the head-shield, or supported by a squamosal element, we are as yet without information. The articular cartilage of the left mandible is somewhat indistinctly shown in text-figure 2; that belonging to the right mandible is removable, and has been omitted in the uppermost figure.

On referring to the diagram in fig. 1, it will be seen that the vomerine teeth in *Mylostoma* are succeeded behind by two pairs of palato-pterygoid plates, instead of one only, as in Ceratodonts. Embryology teaches, however, that the discrepancy is apparent, not real; for as shown by Semon,* the dental plates of *Neoceratodus* arise through concrescence of conical denticles, which are at first disposed so as to form two pairs of palato-pterygoid plates, arranged as in *Mylostoma*, these afterwards fusing into one. Clearly, therefore, the upper dentition of *Neoceratodus* passes through an early *Mylostoma*-stage. Further, it will be noted that the peculiar posterior contour of the hindermost pair of plates in *Mylostoma* (the same holds true also for *Dinomylostoma*) is conformable to, and therefore to be associated with, the usual pattern of palato-pterygoid cartilage found in all Dipnoans. Amongst Ctenodipterines this element is ossified, and passes under the name of "upper dentigerous bone"; the fact that it is unossified in Arthrodires agrees with other evidence pointing to their lesser specialization.

The mandibles of *Mylostoma* betray unmistakable indications of a Ceratodont origin, for the functional dental plate is even more sharply demarcated from the supporting splenial than in *Dinichthys* or *Dinomylostoma*. It even bears prominent ridges radiating from the inner margin, which may possibly be a survival of primitive Dipnoan conditions. The presence of intermandibular teeth would be in complete harmony with embryological evidence, and as a matter of fact, certain detached teeth have been somewhat doubtfully interpreted as such by Newberry.† The pair figured by him, however, have every appearance of being vomerine; interpreting them as such, we must confess ignorance of a pair opposed to them in the lower jaw. Amongst Ctenodipterines, *Synthetodus* is the only genus in which symphysial teeth are permanently retained, thus paralleling an evanescent stage of *Neoceratodus*.

Cranial Characters of Arthrodires and Neoceratodus compared.—The most notable peculiarity of the skull in *Neoceratodus*, as compared with Ctenodipterines, is its retention throughout life of a completely closed and almost entirely unossified chondrocranium. The contrast presented by *Dipterus* in this respect is very striking, Traquair's claim being amply supported that this genus attained a higher grade of

*Semon, R., Die Zahnentwickelung des Ceratodus forsteri. Zool. Forschungsreisen in Australien. Jena Denkschr., vol. iv (1901), pp. 115-133.

†Newberry, J. S., Palæozoic Fishes of North America, Monogr. U. S. Geol. Surv., vol. xvi (1889), p. 165, pl. xvi, fig. 4.

specialization than any existing Dipnoid.* But in Arthrodires, on the other hand, all available evidence goes to show that the skull was constructed upon essentially the same model as in *Neoceratodus;* consequently the latter serves as a most valuable criterion for interpreting various structural details which have heretofore been misunderstood. So far as can be determined from the interior of the headshield in *Macropetalichthys*,† *Chelyophorus*,‡ *Homosteus*§ and a few other genera, the chrondrocranium of Arthrodires was even less ossified than in *Neoceratodus*. It is certain that the parasphenoid was largely cartilaginous, and for all that appears to the contrary, the palato-pterygoid elements must have remained entirely so. The presence of a pineal gland, sometimes but not always communicating with the external surface, is clearly indicated in the Arthrodiran skull, its position being as in *Neoceratodus*. There are also conspicuous ridges on the under side of the cranial shield, both in Arthrodires and in *Neoceratodus*, which extend forwards and inwards from the posterolateral angles, and give off descending processes in front. These are seen in the recent form to furnish support for the palato-pterygoid dental plates. Herein we have an explanation for the great solidity of these ridges in *Dinichthys*, for it can scarcely be doubted that they served a corresponding function as regards the powerful shear-teeth of that form.

We have next to speak of the dermal bones forming the cranial roof. Their origin is admitted to have been through fusion of numerous small dermal plates; but that which is truly remarkable, and claims our closest attention, is that the primordial *Dipterus*-like plates should have become reduced practically to the same extent, and rearranged almost exactly in the same fashion, both in Arthrodires and *Neoceratodus*. When was this simplification brought about? Amongst Ctenodipterines, despite their specialization in other respects, we know that the mosaic pattern of cranial roofing bones persisted as late as the Carboniferous. Amongst Arthrodires, reduction had already taken place in the lower Devonian, after which a fairly uniform pattern was adhered to. Amongst Ceratodonts, we have yet to learn how their cranial plates were arranged anterior to the Trias. Manifestly modern Dipnoans cannot be derived from *both* Ctenodipterines and Arthrodires; and if descendants of the former, how are we to explain the extraor-

* Traquair, R. H., On the genera Dipterus, Palædaphus, Holodus, etc., Ann. Mag. Nat. Hist., ser. 5, vol. ii (1878), p. 5.

† Cope, E. D., On the Characters of some Palæozoic Fishes, Proc. U. S. Nat. Mus., vol. xiv (1891), p. 453, pl. xxix.

‡ Eichwald, E. von, Lethæa Rossica, vol. i (1860), p. 1529, pl. lvii, figs. 1, 2.

§ Woodward, A. S., Note on some Dermal Plates of Homosteus, Proc. Zool. Soc., 1891, pp. 198–201.

dinary resemblance between them and Arthrodires as regards cranial osteology, to say nothing of other skeletal features? But if modern forms are not directly descended from either

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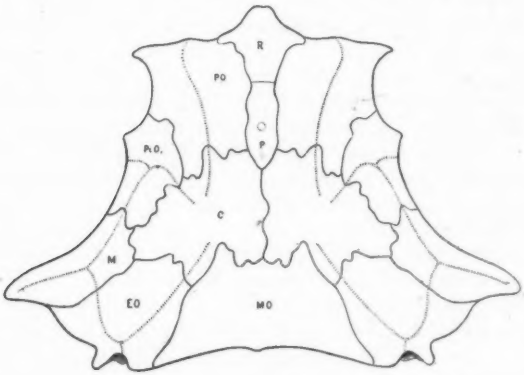

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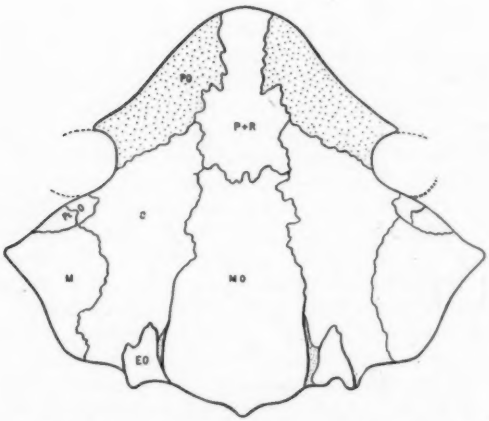

Fig. 3.—*Dinichthys pustulosus* Eastm. Middle Devonian; Iowa. Restoration of the headshield, dorsal aspect. x ¼.

Fig. 4.—*Neoceratodus forsteri* Krefft. Dorsal aspect of cranial roof, drawn as if flattened out. Cartilaginous portions dotted. x ½.

of these groups, if their ancestry can be projected backward in imagination to the starting-point from which both of them diverged, then these difficulties become reconciled, real homologies are established between all three groups, and two of them are seen to have elaborated similar cranial patterns.

Space is wanting to enter into detailed comparisons of the cranial roofing plates as they occur in Arthrodires and modern Dipnoans, but it will be evident from the annexed figures that there is marked agreement between them. Allowance must of course be made for the fact that some of the elements, such as the pre- and sub-orbitals, remain more or less cartilaginous in the modern form. The centrals, also, have become enlarged, much more so than in the Triassic *C. sturii*, and excluded from contact with each other in the median line though elongation of the median occipital. Yet the latter element is relatively less elongated than in *Homosteus*, and *Macropetalichthys* affords a parallel example of fusion between the pineal and rostral. Turning to *Protopterus*, we find that the bones corresponding to the centrals are actually in contact for a certain distance anteriorly, and those of *C. sturii* have practically the some conformation as in *Dinichthys*. In all known Dipnoans, recent and fossil, two opercular bones are present, but these remain for a time fused together in the young *Neoceratodus*. *Coccosteus*, and *Dinichthys* as well, is commonly understood as having one opercular element; Jaekel, however, affirms the existence of two in the former genus.* The significance of this observation, if confirmed, is apparent.

Axis and Body-armoring.—Both in living Dipnoans and amongst all Arthrodires where the vertebral column is known, the latter remains notochoral, and the neural and haemal arches, together with the dorsal fin-supports, have expanded extremities. The resemblance between *Coccosteus* and *Neoceratodus* in this respect is very great. The encasement of the anterior portion of the trunk in dermal armor is to be looked upon as a specialized feature peculiar to Arthrodires, yet comparable, in a general way, to the extensive ossification observed amongst Ctenodipterines, and to the ganoine investment of their squamation. The question of body-armoring is of purely secondary importance in determining affinities, inasmuch as wide variation prevails amongst closely related forms. So far as we may rely on negative evidence, *Macropetalichthys* and *Asterosteus* were unprotected by abdominal armor, and within a single family of Ostracophores, *Pterichthys* is scaled, *Bothriolepis* naked. The fact that two of the dermal covering plates are articulated with the headshield should occasion no surprise, when it is remembered that the so-called "cranial ribs"—which may represent morphologically a pair of costal elements—articulate with the skull in modern Dipnoans.

Fins.—Many writers have taken it for granted that the tail of *Coccosteus* was heterocercal. Not a particle of evidence

*Jaekel, O., Ueber Coccosteus und die Beurtheilung der Placodermen, Sitzungsber. Gesellsch. Naturf. Freunde, Jahrg. 1902, p. 109.

exists in favor of this supposition; on the contrary, authorities like Traquair and Smith Woodward agree that it may as well have been diphycercal. Now it still remains to be proved that the diphycercy of *Neoceratodus* is not a primitive feature, that does not faithfully reproduce ancestral characteristics. One is, indeed, at perfect liberty to believe that the tail of Ceratodonts and Arthrodires never advanced beyond the diphycercal condition, *Dipterus* and its allies alone becoming heterocercal. Inasmuch as the median fins of *Coccosteus* are well separated, their continuity in *Neoceratodus* would seem to be a secondarily acquired character; but the burden of proof surely rests on those who hold that original heterocercy has become suppressed through abortion of the extreme end of the axis, and coalescence of the dorsal and anal fins.

No enlightenment could be more welcome than that which would acquaint us with the structure of the paired fins in Arthrodires, as to whether they were biserial or uniserial, Crossopterygian-like or Pleuracanthus-like. Of the pectoral pair no trace whatever has been preserved, nor do we even know that a girdle was present. Failure of the latter to be preserved might be attributable to a cartilaginous condition resembling that of *Neoceratodus*, but we should expect to find at least some traces of fin rays, were these structures developed. Complete atrophy of the pectoral pair would indicate, of course, high specialization. Obscure traces of a pelvic pair have been detected in some specimens of *Coccosteus*, but nothing is known of their configuration or structure. There seems to be no doubt as to the occurrence of a pelvic arch, and all that different writers have affirmed of it is consistent with the view that it was constructed essentially as in modern Dipnoans. In the latter it has remained cartilaginous; in *Coccosteus* and *Dinichthys* it was ossified.

Conclusions.—The aggregate of facts brought together through comparison of Arthrodires with modern Dipnoans seems to uphold the following general propositions:

1. *Neoceratodus* bears intimate resemblances to Arthrodires on the one hand, and to Ctenodipterines on the other, but represents a more primitive structural type than either.

2. It is impossible to regard *Neoceratodus* as the degenerate descendant of *both* the earlier, more specialized groups, nor of either of them to the exclusion of the other; since, however, it partakes of the characters of both, community of origin is necessarily presupposed for all three orders, Sirenoids, Ctenodipterines and Arthrodires.

3. Arthrodires and Ctenodipterines may be regarded as specialized offshoots which diverged in different directions from primitive Dipnoan ancestors; and the more generalized

descendants of these latter have alone survived until the present day.

4. The primitive stock must have been autostylic, diphycercal, without a secondary upper jaw and dentigerous dentary elements, and with *Uronemus*- or *Dipterus*-like type of dentition; characters which do not permit us to ascribe the ultimate origin of Dipnoans to the Crossopterygii, but suggest rather a descent from *Pleuracanthus*-like sharks.

5. The recognition of Arthrodires as an order of Dipneusti precludes their association with Ostracophores in any sense whatever. The "Placodermata," as originally understood by M'Coy and Pander, is therefore an unnatural assemblage, and should be abandoned.

EXPLANATION OF FIGURES.

Fig. 1. Reconstruction of the upper dentition of *Mylostoma variabile* Newb., from the Cleveland shale of Ohio. The small obtuse vomerine teeth are succeeded behind by two pairs of palato-pterygoid dental plates, as in the young of *Neoceratodus*. The dotted lines are intended to indicate the position of the supporting palato-pterygoid cartilage. x ½.

Fig. 2. Mandibles of *Dinomylostoma beecheri* (MS.), from the Portage beds of Mt. Morris, N. Y. Both the right (*a*) and left (*b*) mandibles are shown from the lateral, external aspect. The posterior portion of the splenial in *b* is seen to have the compressed articular cartilage attached to its outer side. x ½.

Fig. 3. Restoration of the cranial shield in *Dinichthys pustulosus* Eastm. from the Middle Devonian of Iowa. *C*, central; *EO*, external occipital: *M*, marginal; *MO*, median occipital; *P*, pineal; *PO*, preorbital; *PtO*, postorbital; *R*, rostral or mesethmoid. Sensory canals represented by double dotted lines. x ¼.

Fig. 4. Cranial roof of the recent *Neoceratodus forsteri* Krefft, drawn as if flattened out, and dermal plates lettered to correspond with those of *Dinichthys*. The anterior median plate is commonly termed mesethmoid. x ½.

Harvard University,
Cambridge, Mass.

Art. X.—*A New Name for the Dinosaurian Genus Ceratops;* by Richard S. Lull.

In a recent letter to Professor Osborn, Mr. T. D. A. Cockerell calls attention to the fact that the name *Ceratops*, used by Professor Marsh in 1888, for a genus of horned dinosaurs, was preoccupied by Rafinesque in 1815, who thus designated a genus of birds.

The dinosaurian genus is a well-defined one from the Judith River beds of Montana and their equivalent, the Belly River of Canada; the chief generic characters as set forth by J. B. Hatcher* being as follows: "Parietals reduced to a narrow median bar and slender postero-lateral processes, enclosing on either side large elongated parietal fontanelles. External branches of parietals overlapped by the elongated and triangular squamosals. Supraorbital horn cores well developed, circular in cross section except near the base, and curving backward and outward. Nasal horn core strong and curved forward instead of backward as in *Monoclonius*."

The type species is *Ceratops montanus* Marsh, and Hatcher also included in the genus *Monoclonius recurvicornis* Cope, *M. canadensis* Lambe, and *M. belli* Lambe. *Ceratops paucidens* Marsh, Hatcher abandoned owing to the nature of the type material, which was such as to preclude precise definition.

This genus is quite distinct from *Monoclonius* and *Centrosaurus*, its contemporaries, and from the Laramie genera *Agathaumas*, *Triceratops*, *Diceratops* and *Torosaurus*.

The name *Proceratops* is offered as a substitute for *Ceratops* as suggestive of the latter name and as indicating the forerunner of the great horned dinosaurs of the Laramie. This necessary change would seem to invalidate Marsh's family name of Ceratopsidæ given in 1888 and necessitate the use of Cope's term Agathaumidæ (1889) for the group.

Amherst, Mass.

* Bulletin of the U. S. Geological Survey, No. 257, p. 93.

Art. XI.—*On the Interlocking of Emarginate Primary Feathers in Flight;* by C. C. Trowbridge.

This paper contains the results of observations showing that certain birds interlock the emarginate primary feathers of their wings in flight. Some of these observations were made a number of years ago, but were withheld from publication until sufficient evidence could be collected to demonstrate conclusively the existence of this principle of animal mechanics. The additional evidence has been obtained and the complete paper is now presented.

A paper published in 1887, entitled "Something New About the Flight of Birds,"* contained a short account of an observation which I made during the autumn of 1885; namely, that on several occasions some of the primary or long end feathers of wings of hawks were found interlocked when these birds were killed while in flight. The primaries found interlocked were those which were emarginate, that is, having their webs narrowed half way to the tips (as shown in fig. 1), the feathers being interlocked in the emarginations.

The essential facts of the observation were also presented by my father, the late Professor W. P. Trowbridge, before the National Academy of Sciences and the New York Academy of Sciences, and shortly afterwards a controversy on the subject took place in *Science* between the late Dr. Elliot Coues, who opposed the hypothesis that the primaries were interlocked in flight,† and the late Professor J. S. Newberry and Professor Trowbridge, who took a strong stand in its favor.‡ Investigation of the subject has been continued by me with the purpose of obtaining further facts.

In September, 1891, at New Haven, Conn., during the migrations,§ a large number of hawks were killed and examined as soon as they fell to the ground. The observations on one occasion were assisted by my father and on another by Mr. Henry Townsend of New Haven. These and later observations have been presented before the New York Academy of Sciences but have not been published heretofore.

The alleged interlocking or overlapping of the primaries has been repeatedly disputed by prominent ornithologists, a fact which has caused me to defer the publication of a paper on the subject until I could decide the question positively.

* C. C. Trowbridge, O. & O., vol. xii, No. 12, p. 202.
† Sci., vol. x, No. 256, p. 321. ‡ Ibid., vol. xi, No. 257, p. 9.
§ C. C. Trowbridge, Hawk Flights in Connecticut. The Auk, xii, No. 3, July 1895.

This paper contains the following sections:

I. Emarginate primaries, their form and inter-relation.
II. Observations made at New Haven, Conn., in 1891, showing the interlocking of the primaries in certain species.
III. Observations made at New Haven, Conn., and at Paterson, N. J., in 1904–5.
IV. Measurements of the notches in the emarginate webs, showing how long the primaries were interlocked.
V. Species which have emarginate primaries.
VI. Three well-defined types of flight in Raptores.
VII. Function of interlocked primaries in flight.
VIII. The wear of the primaries as shown by the microscope.
IX. Summary and Conclusions.

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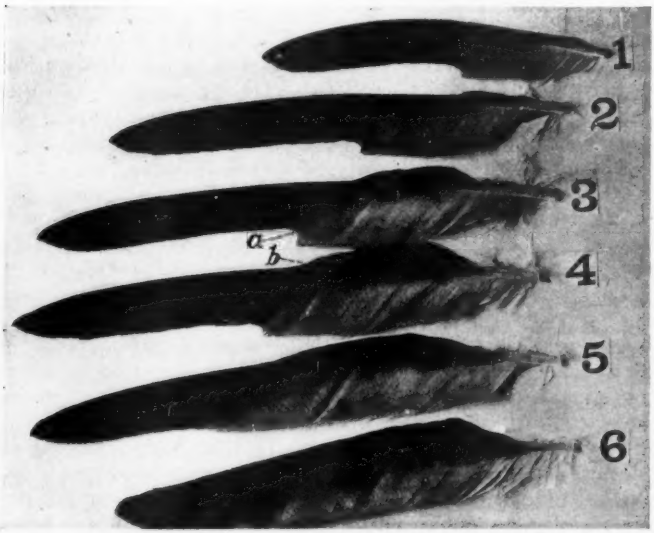

I. Emarginate Primaries, their Form and Inter-relation.

The number of primary feathers of the wing that are emarginate in different species is often used as one of the means of identification in standard works on ornithology. The emarginate shape of these feathers is natural and not produced by wear, as is well known. It is very marked in eagles and hawks and other birds of prey. In some species, six out of ten primaries are deeply emarginate on the posterior web.

A complete set of emarginate primaries of a common hawk (*Buteo lineatus*) are shown in fig. 1. In this species the first

primary (1) is emarginate only on the posterior web, and the fifth primary (5) emarginate only on the anterior web, while the three other primaries (2, 3 and 4) are emarginate on both webs. The sixth primary (6) is not emarginate and is shown for comparison. The emarginate contour of the anterior web is sometimes called "sinuate."* When the primaries are in their natural places in the wing the emargination of the anterior web in every case exactly corresponds to the emargination of the posterior web of the preceding feather, and permits the feathers to be easily and firmly interlocked at the points on the webs where the emarginations begin. (See *a* and *b*, fig. 1.) This correspondence is characteristic and demonstrates the inter-relation of emarginate primaries.

To illustrate the way in which primaries are interlocked, the five outer primaries of a Red-shouldered hawk are shown as they appear when they are not interlocked, as seen from beneath the wing, in fig. 2, and then as they are when interlocked in fig. 3. The same set of primaries as seen from above the wing are shown in figs. 4 and 5.

The primaries may be more widely separated than they appear in these figures and yet be firmly interlocked, especially in the case of large birds where the feathers are long in proportion to their rigidity. Under these circumstances the emarginate portions of the primaries are usually curved slightly upward by the pressure of the air. This upward curve has often been observed.

II. Observations made at New Haven, Conn., showing the Interlocking of Primaries in Certain Species.

In September, 1891, during the hawk migrations of that year, about thirty hawks were killed, examined as soon as they had fallen to the ground, and the number of primary feathers interlocked recorded. These observations are given in Tables I and II, in which the columns marked A and B refer to the wings of the bird, because the wings were not designated by "right" and "left" when the observations were made. The hawks were shot as they were passing over a high hill southeast of New Haven, Conn.

Large migratory flights of hawks have occurred along the coast of Connecticut nearly every autumn, the greatest flights having taken place in September. On numerous occasions many thousands hawks have passed during a day, when flocks of upwards of one hundred of certain species have been observed. In the opinion of the writer, the time of these extensive migratory movements is directly dependent upon the direction and velocity of the wind. If the wind starts to blow

*E. Coues, Key to N. Amer. Birds.

2, 3, 4, 5

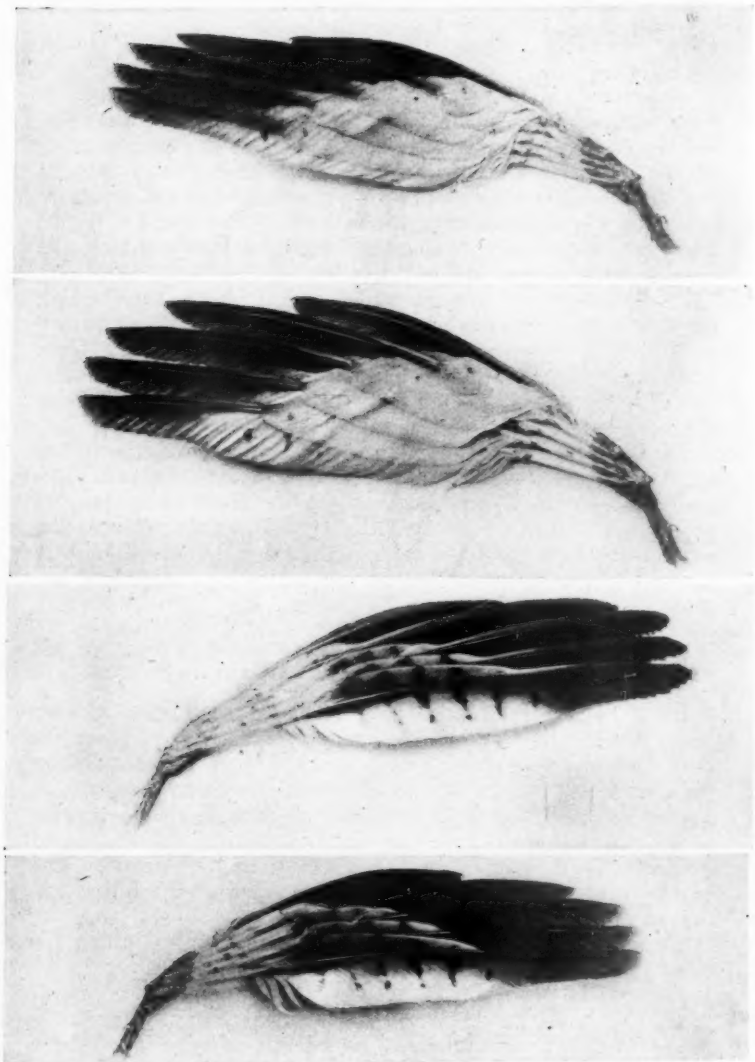

FIG. 2. Primaries not interlocked, viewed from beneath the wing.
FIG. 3. Primaries interlocked, viewed from beneath the wing.
FIG. 4. Primaries not interlocked, viewed from above the wing.
FIG. 5. Primaries interlocked, viewed from above the wing.

from the north, northeast or northwest, hawks immediately appear in large numbers. Records seem to show that these birds utilize the wind as a means of migration, and that they begin their migration movements independently of changes of temperature that occur.* The hawks that were shot had been migrating for hours, alternately soaring and coasting, and were killed as they passed over one of the high hills near the coast. During the migration, where a portion of the journey is against the wind, if hawks approach a hill in line of their flight, they usually coast with set wings and descending pass rapidly over the crest of the hill close to the ground. Having passed the crest of the hill they almost invariably soar until they have ascended many hundred feet, apparently using the upward air currents that exist on the windward slope. They then again coast towards the next hill that lies in the direction in which they are migrating.

In a few places the coast line is at right angles to the direction of migration. At these points in the migratory route the hawks often fly almost against the wind. Where the wind is favorable the hawks migrate at an altitude of a thousand feet or more.

The observations at Paterson, N. J., in the spring (Table III, etc.) have been made when hawks are moving northward, migrating in the manner just described.

This brief description of the way in which the Falconidæ make their migrations has been given to show the conditions under which the observations recorded in this paper have been made. All the hawks obtained were killed during the migrations.

An examination of Table I shows the following significant facts: —

Number of perfect wings of 23 specimens of one species examined	40
Number of wings found with some primaries interlocked	40
Number of wings with five (all) primaries interlocked	10
Number of wings with four primaries interlocked	8
Number of wings with three primaries interlocked	11

Thus 29 out of 40 wings were found to have an average of 76 per cent of their emarginate primaries interlocked.

Total number of emarginate primaries of perfect wings	200
Total number of emarginate primaries of perfect wings interlocked	134
Percentage of primaries found interlocked	67.0%

*C. C. Trowbridge: Relation of Wind to Bird Migration, Amer. Nat., xxxvi, 429, Sept., 1902.

TABLE I.

Sharp-shinned hawk (*Accipiter velox*) (5 outer primaries emarginate). Number of primaries interlocked in columns A and B.

No.	Date.	A wing.	B wing.	Both wings.	Remarks.
1	Sept. 8, 1891	2	2	4	
2	" " "	3	3	6	
3	" " "	4	--	4	Wing B badly shot
4	" " "	5	3	8	
5	" " "	--	--	--	Both wings badly shot, some primaries interlocked
6	" " "	5	5	10	
7	" " "	3	4	7	
8	" " "	5	5	10	
9	Sept. 9, 1891	4	5	9	♀
10	" " "	3	2	5	
11	Sept. 14, 1891	1	--	1	Wing B moulting
12	" " "	2	3	5	♀
13	" " "	2	3	5	♀
14	" " "	4	4	8	♂
15	" " "	4	5	9	
16	" " "	5	1	6	
17	" " "	0	0	0	Hawk wounded, record not possible
18	" " "	4	3	7	
19	" " "	1	2	3	
20	" " "	5	3	8	
21	" " "	4	2	6	♀
22	" " "	5	2	7	♀
23	" " "	3	3	6	♀
	Total	74	60	134	

TABLE II.

Osprey, (*Pandion haliætus carolinensis*) 4 outer primaries emarginate.
Marsh hawk, (*Circus hudsonius*) 4 outer primaries emarginate.
Broadwinged hawk, (*Buteo latissimus*) 3 outer primaries emarginate.

Species.	Date.	Number of primaries interlocked. A wing.	B wing.	Both wings.	Remarks.
Osprey	Sept. 8, 1891	0	0		Bird wounded, no record
Osprey	" 9, "	3	--	3	Wing B broken at tip
Marsh hawk	" 14, "	4	3	7	Young of year
Broadwinged hawk	" 14, "	2	2	4	Young of year

In Table II both wings of the first Osprey were discarded because the bird was wounded, and also one wing injured by shot in the case of the second Osprey, leaving five perfect wings with a total of eighteen emarginate primaries; fifteen, or 83 per cent, of these were interlocked.

III. Observations made at New Haven, Conn., and at Paterson, N. J., in 1904–5.

Since the data of Tables I and II were obtained, many hawks have been shot and at once examined, and the ratio of the number of primaries found interlocked to the number of primaries that are emarginate has been found to be about the same as in the above tables.

The observations given in Table III were made during the past year, and were obtained incidentally while I was engaged in a study of certain notches made in the primaries by the interlocking of these feathers. The observations made on October 27th recorded in this table were on adult birds, all flying low, scudding with half-closed wings against a strong northwest wind. Two of the three fell dead when shot.

The observations in these tables is conclusive evidence that a very large percentage of the emarginate primaries are found interlocked when hawks are killed while in flight.

Table III.

Sharp-shinned hawk, *Accipiter velox*, 5 outer primaries emarginate.

	Date.	Number of primaries interlocked. Right wing.	Left wing.	Both wings.	Remarks.
(1)	Sept. 21, 1904	1	5	6	Young
(2)	" 22, "	5	1	6	Young: deep notches in primaries
(3)	Oct. 27, "	5	4	9	Adult: bird fell dead
(4)	" 27, "	2	2	4	Adult: bird fell dead.
(5)	" 27, "	2	3	5	Adult
(6)	May 1, 1905	3	3	6	Notches in primaries 3mm deep
(7)	" 1, "	(1*)	5	5	Adult: notches 2–5mm deep
	Total	18	23	41	

In this table 41 out of 65 emarginate primaries were interlocked, or 63 per cent. For explanation of notches see next section of the paper.

Specimens 1 to 5 were shot at New Haven, Conn., 6 and 7 at Paterson, N. J.

* Right wing torn by shot and discarded.

IV. Measurement of Notches in the Primary Webs showing how long these Feathers were interlocked.

It has been suggested that the interlocking of the feathers in the many instances which have been recorded was accidental and took place while the birds were falling to the ground. Perhaps a few primaries were thus accidentally interlocked after the birds were shot; on the other hand, it is probable that as many or more of the emarginate primaries if interlocked while the birds were flying became unlocked when the birds were struck by shot and fell. This matter has been carefully investigated and the fact demonstrated that the feathers interlocked were in that condition either intermittently or continually for several hours previous to the death

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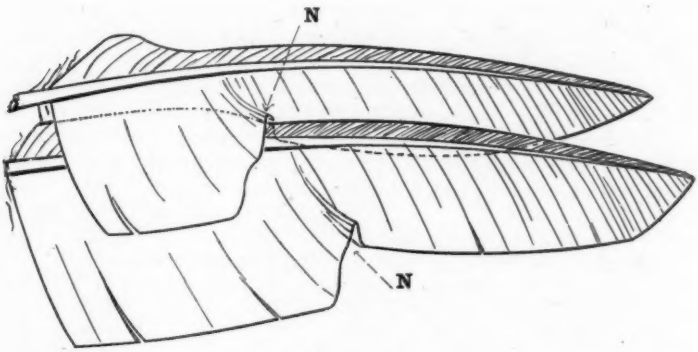

of the birds. Considerable difficulty has been experienced in obtaining the necessary observations. During the past few years not less than thirty trips have been made to a hill five miles from New Haven, Conn., in the autumn, and ten trips to the Watchung Mountain range near Paterson, N. J., in the spring. Many times large numbers of hawks were observed but none could be obtained, owing to the fact that they were migrating with a fair wind at an altitude that was beyond gun range. The observations were finally collected and are given herewith.

When hawks are shot while they are flying, deep notches are found in the edges of the posterior webs of the emarginate feathers that are interlocked. In unlocking the feathers it is necessary to lift them free of these notches. (See N, fig. 6.) The notches are due to the pressure of the feathers which have been in contact. It occurred to me that the immediate disappearance of the notches on unlocking the primaries would

indicate that the feathers had been interlocked a very short time. If, however, the notches remained for a period of minutes or more it would show that the feathers had been interlocked for a longer time. This proved to be the case in experiments which consisted of artificially interlocking the emarginate primaries for different lengths of time. The recovery of the semi-elastic webs of the primary feathers notched by the pressure of the interlocked feathers has therefore been the subject of investigation.

Measurements have been made which consisted in determining the widths of a notch at different intervals of time immediately after the death of a hawk. For the purpose of explanation, in fig. 7 the initial width of the notch is indicated

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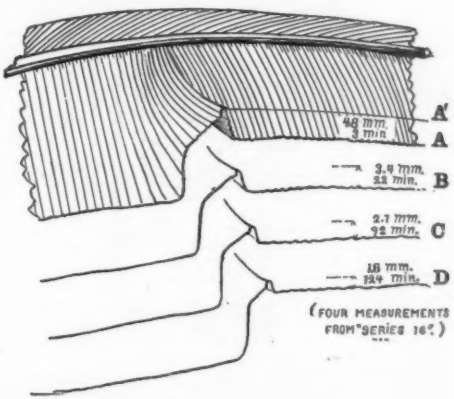

by the distance apart of the lines A and A′, and the gradual diminution in its width is indicated by the notches on the lines A, B, C, and D, which represent the edge of the web of a primary at different intervals of time after the feathers were unlocked.

Method of Measurement.

The method of measurement was as follows: the points of a pair of fine dividers were adjusted to correspond with the width of a notch in a primary as soon as possible after a hawk had been killed. Impressions of the points were then made in a notebook and their distance apart afterwards determined by means of a fine scale. Measurements were made every few minutes in this way until the notch disappeared or ceased to diminish in width.

In the case of Series 4 and 8 a photographic method was employed and the width of the notches measured by means of a Repsold star plate measuring machine loaned for the purpose by the Department of Astronomy, Columbia University. The caliper method was used in subsequent measurements because it was found to be sufficiently accurate.

The method of photographing the primaries consisted in constructing a standard S, as shown in fig. 8, to support both camera C and the primaries P. The latter were held in position by thumb-tacks T. An auxiliary lens, L, was used by which a life-sized image was formed on the film when the object was held on the standard, 15 centimeters from the lens.

Photographs of the notches in the first primary feathers are shown in figs. 9 and 10. The former is one of the photographs of Series 4, a Sharp-shinned hawk. The latter is one of Series

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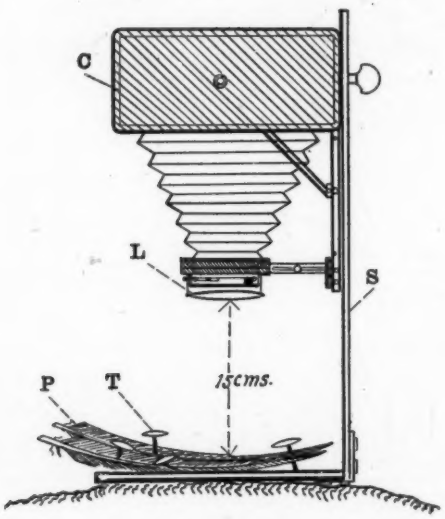

8, an Osprey, which was moulting and the primary had not completed its growth; therefore, the notch is not at the point where the emargination begins, which is the usual case. The photographs given were selected from among those in Series 4 and 8 as giving the best definition for reproduction.

Curves have been drawn from the measurements showing the recovery of the web of the feathers after the pressure caused by the interlocking of the feathers was relieved. Sim-

ilar curves have been obtained by artificially interlocking the primaries for several hours and then measuring the recovery of the web of the feathers with a micrometer microscope. It

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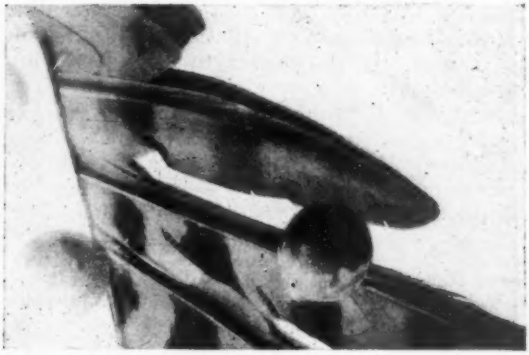

FIG. 9. Notch in the first primary feather of a Sharp-shinned hawk formed by the interlocking of the feathers. Photograph taken 18 minutes after the bird was killed. (Round object is a large thumb tack holding feathers in place.)

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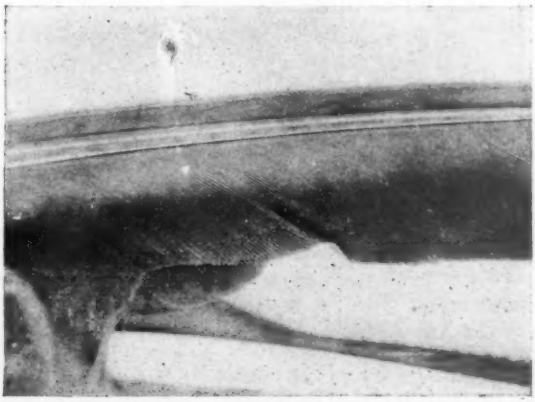

FIG. 10. Notch in the first primary feather of an Osprey formed by the interlocking of the feathers. Photograph taken 60 minutes after bird was killed.

was found that artificial interlocking of the feathers for fifteen minutes produced either no notches or those that were small and rapidly disappearing, while interlocking them for several

hours formed notches only about one-half as deep as those found when the hawks were killed.

As previously stated, the records of the widths of the notches were made by the impression of the points of a pair of dividers, the actual measuring being done in the laboratory afterwards. In this way each measurement was little influenced by the preceding. This naturally resulted in experimental variations, but it seemed to be the best method to employ and the measurements give approximate curves of the rate of recovery of the web of the feathers in each case, which was all that was desired. If the measurement had been mostly confined to the second, third, etc., primaries instead of the less elastic first primaries, more nearly perfect curves would have been obtained, as shown by curves 14, 15 and 16.

TABLE IV.

Recovery of the webs of three primary feathers of a Broad-winged hawk (*Buteo latissimus*) shot at 10.30 A.M., April 13th, 1904, at Paterson, N. J.

Series 1.

Notches found in the primaries of the right wing a few minutes after the bird was shot.

Time after fall of bird. Minutes.	First primary width of notch. mm.	Second primary width of notch. mm.	Third primary width of notch. mm.
0	--	--	--
10 (approx.)	1·1	2·0	1·7
20	0·8	--	1·7
30	0·3	1·0	1·3
40	0·3	0·2	0·8
60	0·3	0·0	0·0

Series 2.

Primaries of left wing artificially interlocked for 30 minutes with strong pressure within one-half hour after death of bird.

Time after unlocking. Minutes.	First primary width of notch. mm.	Second primary width of notch. mm.	Third primary width of notch. mm.
0	2·1	0·4	0
5	1·0	0·0	0

The reason for making sixteen series of measurements was to include every possible condition and to obliterate the effect of experimental errors in the conclusions drawn. The results all point to the fact that wherever notches were found the primaries must have been interlocked for two or more hours. Deep notches are almost always present in primaries that are found interlocked, and, moreover, in almost all of the primaries that are emarginate that are not found interlocked, showing that the latter were unlocked when the birds were shot and fell to the ground.

The results of the measurements are shown by the accompanying tables and curves.

Explanation of Table IV.

Table IV shows the result of observations on the primaries of a Broad-winged hawk. They were the first made, and while the few measurements must be regarded as only approximate they demonstrate the fact that the feathers were interlocked for some hours previous to the death of this bird, as seen from

TABLE V.

Recovery of the web of a first primary feather notched by natural interlocking, specimen: Sharp-shinned hawk (*Accipiter velox*), adult ♂, shot at 2.38 P. M., April 21st, 1904, Paterson, N. J.

Series 3. By calipers.			Series 4. By photography		
Time. h. m.	Time after fall of bird. Minutes.	Width of notch. mm.	Time. h. m.	Time after fall of bird. Minutes.	Width of notch. mm.
2·51	*13	1·85	2·48	10	1·92
2·57	19	1·70	2·56	18	1·80
3·02	24	1·55	3·45	67	1·53
3·10	32	1·50	4·40	122	1·39
3·19	41	1·40	4·50	132	1·16
4·07	89	1·30	5·15	157	1·07
4·30	112	1·0	5·25	167	·98
4·38	120	1·05	10·45	487	·66
4·42	124	1·10			
5·00	142	1·10			
5·20	162	1·1			
9·00	382	·60			
10·40	522	·50			

a comparison of the two series of measurements. The time required for the webs of the feathers artificially interlocked to recover (see Series 2) was very short and the notch was not even formed in one-half hour in the case of the third primary. Before the measurements of Series 2 were made the primaries of the left wing were interlocked for five minutes, but as no notches were formed, the interlocking period was increased to thirty minutes. This bird was shot by a person near me and was handled before I reached it. The primaries were then not interlocked but the notches were very prominent, so their recovery was measured. It was not possible to obtain another specimen of this species of hawk for measurement.

* Time was lost preparing camera for Series 4.

Explanation of Table V and Curves in Fig. 11.

The measurements in Table V were made on one of the first primary feathers of a Sharp-shinned hawk; Series 3 by calipers and Series 4 by photography and a measuring machine. The primaries of the wing of the same bird as that from which Series 3 and 4 were taken were later artificially interlocked and pressed together with constant pressure; then, after having been interlocked for several hours (see fig. 11,

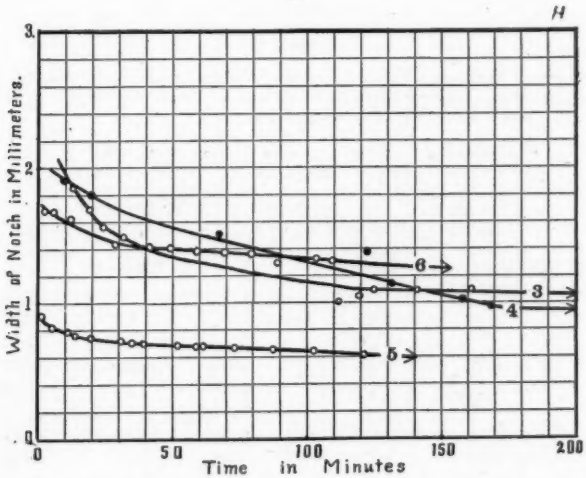

FIG. 11. Series 3 and 4: Recovery of a web of a first primary feather notched by natural interlocking. Sharp-shinned hawk, *Accipiter velox*, Series 3 by calipers, Series 4 by photography, see Table V, primary found interlocked.

Series 5 and 6: Recovery of the webs of first primary feathers of the same bird when the feathers were interlocked by artificial interlocking. Series 5 interlocked for 2 hours 40 minutes, Series 6 interlocked for 4 hours 10 minutes, measurement by micrometer microscope.

Series 5 and 6) the feathers were unlocked and the gradual recovery of the web as shown by the decrease in the width of the notch was measured by means of a micrometer microscope. Series 5 was taken seven days after the hawk was killed and Series 6 was taken about one week later. The notches in the webs of the feathers thus artificially made are seen to be less in width than the notches found in the webs of the feathers which were naturally interlocked (Series 3 and 4). The rate of recovery is approximately the same as is also the form of the curves, as in Series 3 and 4.

Explanation of Table VI and Curves in Fig. 12.

In Table VI, Series 7, first primary of an osprey was made by calipers and Series 8 by photography and a measuring machine. These series are shown by curves in fig. 12. It should be kept in mind that the purpose of the measurements was to determine the rate of diminution of the width of the notches rather than their exact width. The width of the notches in Series 7 and 8 are not equal, because it was not possible to take the photographs exactly life size. The rates of decrease of 7 and 8 are seen to be the same.

TABLE VI.

Recovery of the web of a first primary feather notched by natural interlocking. Osprey (*Pandion haliaetus carolinensis*), shot at 3.45 P. M., April 21, 1904, at Paterson, N. J. First primaries of each wing found deeply notched.

Series 7. By calipers.			Series 8. By photography		
Time. h. m.	Time after fall of bird. Minutes.	Width of notch. mm.	Time. h. m.	Time after fall of bird. Minutes.	Width of notch. mm.
3·49	4	3·3	4·00	15	3·22
4·00	15	2·5	4·08	23	2·85
4·08	23	2·4	4·45	60	2·84
4·30	51	2·4	5·05	80	2·76
4·45	60	2·1	5·20	95	2·72
5·00	75	2·2	10·45	420	1·67
5·20	95	2·1			
9·00	315	1·6			
11·45	480	1·2			

The primaries of the same bird were then artificially interlocked. The measurements of the resulting notches are also shown in fig. 12. Series 9 was made two days after the bird was killed, and Series 10 several days after that.

Explanation of Table VII and Curves in Fig. 13.

In fig. 13, Series 12, is merely a verification of previous observations, the species being a Sharp-shinned hawk; and likewise Series 13.

Series 14 and 15, Table VII, are important since they show the rate of change in the depth of the notch found in the second and fifth primaries of a Sharp-shinned hawk. The webs of these feathers are seen to be more elastic than those of the first primaries and the recovery is more rapid and complete. The feather structure of the first primary is very rigid and therefore its web not only requires a long time to recover

from the pressure of the adjacent primary but usually a small permanent notch remains, 10 or 15 per cent of the initial width.

Series 12, 13, 14 and 15 are shown by curves in fig. 13.

On September 21st, 1905, a specimen of the Marsh hawk, *Circus hudsonius*, was killed at New Haven, Conn. The bird was shot after it had been coasting for several hundred yards

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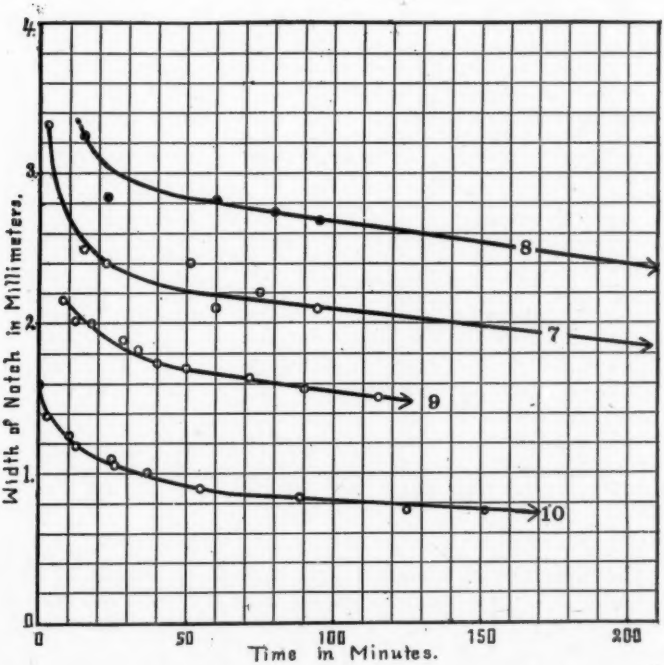

FIG. 12. Series 7 and 8: Recovery of the web of a first primary feather notched by natural interlocking. Osprey, *Pandion haliaetus carolinensis*. Series 7 by calipers, Series 8 by photography, see Table VI.

Series 9 and 10: Recovery of the webs of the first primaries of the same bird when the feathers were notched by artificial interlocking. Series 7 for 1 hour strong pressure, Series 10 for 3 hours light pressure.

toward the hill on which the writer was stationed. The left wing was broken near the shoulder; the four (all) emarginate primaries of this wing were interlocked. The right wing primaries were partly interlocked, but shot had cut the feathers, and all the emarginate primaries of both wings had notches in them from four to six millimeters in width.

TABLE VII.

Recovery of the webs of the 2d and 5th primaries, notched by natural interlocking, specimen: Sharp-shinned hawk (*Accipter velox*), adult ♂. Shot at 11.49 A. M., Oct. 27, 1904, New Haven, Conn.

Series 14. 2d primary r. wing.			Series 15. 5th primary r. wing.		
Time. h. m.	Time after fall of bird. Minutes.	Width of notch. mm.	Time. h. m.	Time after fall of bird. Minutes.	Width of notch. mm.
11·52 A. M.	3	1·1	11·55 A. M.	6	2·1
11·55	6	0·9	11·56	7	1·7
11·58	9	0·8	11·58	9	1·4
12·01 P. M.	12	0·7	12·02 P. M.	13	1.1
12·02	14	0·8	12·04	15	1·0
12·07	18	0·7	12·09	20	0·9
12·14	25	0·6	12·18	29	0·8
12·26	37	0·6	12·27	38	0·7
12·40	51	0·7	12·40	51	0·5
1·16	87	0·4	1·16	87	0·4

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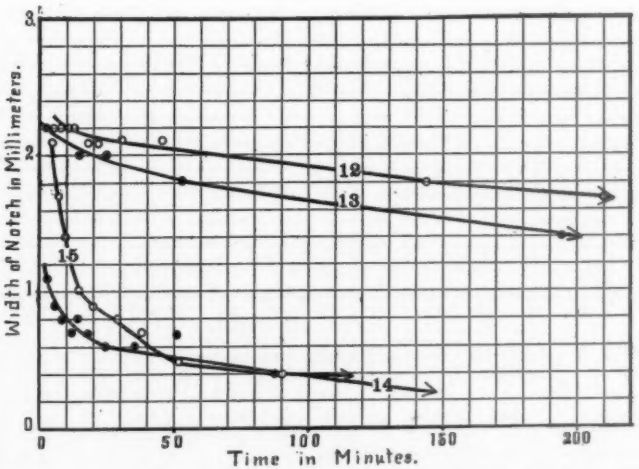

FIG. 13. Series 12: Recovery of the web of the first primary feather, right wing, of a Sharp-shinned hawk, *Accipiter velox*. Shot Sept. 21, 1904, 10.58 A. M., New Haven, Conn. Feather found interlocked.

Series 13: Recovery of the web of a first primary feather of a specimen of the same species, shot Sept. 22, 1904, 9.24 A. M., New Haven, Conn. Feather found interlocked.

Series 14 and 15: Recovery of the webs of primaries of a specimen of the same species, shot Oct. 27, 1904, 11.49 A. M., New Haven, Conn. Series 14, second primary right wing; Series 15, fifth primary, right wing. Feathers found interlocked. See Table VII.

The primaries of the left wing were lifted out of the notches and the third primary subjected to measurement. The recovery of this feather from the pressure caused by the interlocking is shown in Series 16, fig. 14. The notches in the other feathers were as wide as the feather measured and disappeared gradually approximately at the same rate. It is seen that the notch decreased in width from 4·8 to 1·8 millimeters in about two hours. In the case of this hawk a little over two minutes were lost before the feather was unlocked and subjected to measurement, but it has already been shown that it requires

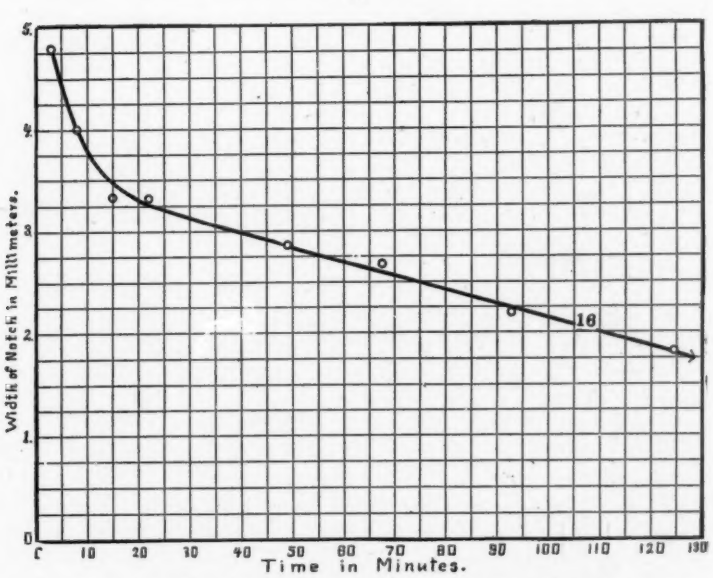

FIG. 14. Series 16. Recovery of the web of the 3d primary of the left wing of a Marsh hawk, *Circus hudsonius*, shot Sept. 21st, 1905, 9.26 A. M., at New Haven, Conn. 1st–4th primaries of left wing found interlocked.

ten to twenty minutes to form the smallest notch. So that this time (2 minutes) was a small factor in the time of forming the notch.

V. SPECIES WHICH HAVE EMARGINATE PRIMARY FEATHERS.

The emarginate formation of the primaries is more pronounced in the *Raptores* than in any other birds, especially in the case of the sub-order of *Accipitres*, or diurnal birds of prey, eagles, hawks, etc. Some of the family of *Cathartidae* or American vultures have a number of their primaries emar-

ginate, a few of the family *Ardredae* or herons, birds that frequently both soar and coast, and other large-winged waterfowl. In case of a few small birds, notably some of the family *Tyrannidae*, or flycatchers, one or two of the primaries are emarginate. These birds are "insect hawks" and dive and sail with set wings for their prey, and the formation may be more than rudimentary in this case.

In almost, if not in every instance where emarginations are present, the species is one which frequently coasts with set wings or dives through the air. In many species the emarginate formation of the primaries is present but in far less degree than in those above mentioned. In a large number it is rudimentary or wanting.

Important examples of North American species having emarginate primaries are as follows:

The Bald Eagle, *H. leucocephalus*, and Golden Eagle, *A. chrysaetus*, each have six primaries deeply emarginate, the Osprey, *P. haliaetus carolinensis*, having four. The *Buteos*, or buzzard hawks, have three to five primaries emarginate. In early editions of Coues' Key of North American Birds this sub-family was classified as follows: "Heavy weights five outer primaries cut," containing one example, now *Parabuteo unicinctus harrisi:* Harris's Buzzard, "Heavy weights, four outer primaries cut," *B. albocaudatus sennetti*, *B. borealis*, the latter the familiar large Red-tailed hawk, and several varieties of this species.

Light weights; "four outer primaries cut," *B. lineatus*, *B. abbreviatus*, etc.

Light weights: "three outer primaries cut," comprising *B. swainsoni* and *B. latissimus*, the second being the Broad-winged hawk mentioned frequently in the present paper.

In the sub-genus *Archibuteo* the species have from two to five outer primaries emarginate, and in *Asturina* or hawk-like buzzards, four.

In the sub-family *Accipitrinae*, or the true hawks, the number of emarginate primaries are *A. atricapillus* 4, *A. cooperi* 4, *A. velox* 5.

In the sub-family of *Falconinae*, or falcons, the first one or two outer primaries are emarginate. In the sub-family of *Milvinae*, or kites, *R. sociabilis*, or the Everglade kite, has five outer primaries emarginate, the other species in this sub-family having but two primaries emarginate.

In the case of the sub-order *Striges*, or owls, the number of emarginate primaries varies from one to six; some examples are as follows; *S. cinerea* (Great grey owl of Canada) has five outer primaries emarginate, *S. nebulosa* 4, *N. nyctea* (Snowy owl) 4, *M. asio* 4, *B. viginianus* 3, *A. wilsonianus* 1, *A. accipitrinus* 1.

VI. Three well-defined Types of Flight in Raptores.

Three distinct types of flight employed by birds of prey, herons and various other large birds, are as follows:

(1) Periodic wing beats; in which for a part of the stroke at least the primaries are fully extended.

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(2) Soaring (in circles): in which the wing is widely extended and the primaries may or may not be extended, depending on conditions of wind, etc.

(3) Coasting with set wings. In this case the primaries are partly extended only, as shown in fig. 15. Diving through the air differs only in degree from coasting but in this case the wing is partly closed, the primaries nearly flexed and the

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tail often closed, steering being aided by the wings, as in fig. 16. Of course birds often combine these types, i. e., alternating periodically (1) and (2), or (1) and (3). Coasting flight is one that is employed by Raptores, herons, gulls, etc., continually, both during their migrations and in their daily evolutions.

During the autumn I have often watched flocks of from twenty-five to seventy-five Broadwinged hawks coasting together for a distance of upwards of half a mile without beating their wings; this maneuver, characteristic of their manner of migration, was periodically repeated after a short interval of soaring.

VII. The Function of Interlocked Primaries in Flight.

In coasting flight: The primary feathers, the most important feathers of the wing, are subjected to great strain and pressure. The backward pressure on these feathers is particularly great under the following conditions: (1) When a bird is sailing or coasting through the air with set wings, fig. 15. (2) When it is diving or twisting in pursuit of its quarry as in birds of prey, fig. 16. In both cases some means of producing rigidity in the end of the wing seems necessary.

In these types of flight the interlocking of the primaries would make the end of the wing very rigid, thereby not only forming a strong surface to withstand the pressure of the air, but when the primaries are interlocked no muscular force is required to keep them partially extended. In addition, the shape of the wing is curved by the process of interlocking, figs. 18 and 19, in such a way that the lower rather than the upper surface of the feathers bears the pressure of the air when the bird is coasting or diving; the effect of the interlocking of the primaries appears to make a much more efficient aeroplane of the wing than when the primary feathers are not interlocked.

No special set of muscles is required for interlocking the primaries. In coasting flight, if these feathers are extended and then allowed to fall back, the pressure of the air forces the end of each primary above the plane of the succeeding primary and those that are emarginate become interlocked. These feathers can usually be interlocked artificially by holding an open wing in the hand and striking the air with it as in a downward wing beat.

In soaring flight (circling): Whether the emarginate primaries are interlocked in soaring flight or not is an undecided question.

Photographs and visual observation of Turkey buzzards and other large birds show the primaries considerably separated when these birds are soaring, but this is by no means evidence that the feathers are not sufficiently overlapped to keep them in place without muscular effort.

When a bird is soaring in a light wind the air pressure acts on the primaries almost entirely from beneath. The outer primaries of large birds while soaring have been observed to

be bent upwards by the air pressure. They are then not only extended in a horizontal plane but also separated to some extent in a vertical plane. Under these circumstances while the primaries would appear widely apart, they might readily

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FIG. 17. Primaries not interlocked, viewed from in front of the wing.

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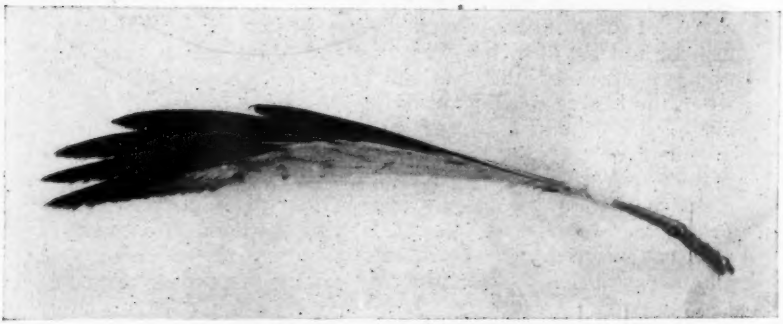

FIG. 18. Primaries interlocked, viewed from in front of the wing.

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FIG. 19. The bowed effect of the wings is seen in many species in swift coasting flight. The twist of the wing is shown as given by Pettigrew.*

be held in an extended position, or in other words interlocked, by the emarginations, thus forming a firm stepped aeroplane at the end of the wing.

* Pettigrew, Animal Locomotion, p. 186 and 198.

VIII. The Wear of the Primaries as seen by the Microscope.

The primaries of a number of hawks killed when their plumage was at various stages of wear, were subjected to microscopic examination. In this way it was hoped to determine if the primaries had become worn by habitual interlocking, or by the absence of any wear to find an argument against any such interlocking,

It was found that the wear of the extreme edge of the posterior webs of the emarginate primaries began very shortly after they had completed their growth, that is, after the moult. Also that a general breaking of the feather structure all along the edge of the webs in most cases obscured any special wear at any particular place. In a number of cases, however, the webs of the feathers, where the webs touched when interlocked, were completely broken down, apparently showing wear from constant contact or pressure. Owing to the uncertainty of this evidence, no further observations were made.

IX. Final Summary and Conclusions.

The most salient facts established in this paper are as follows:

(1) Of over thirty hawks killed while in coasting flight, which were examined immediately after they fell, in every case some emarginate primaries were interlocked (several slightly wounded birds not included). In the case of 27 specimens of one species, 175 out of all emarginate primaries (270) were found to be interlocked, or about 65 per cent. Other observations agree approximately with this ratio. Many hawks, including seven species not recorded in this paper, have been shot and found with their primaries interlocked by the writer and others. There is, therefore, conclusive evidence that when hawks are killed while in flight, of certain types, a large percentage of the emarginate primaries are found firmly interlocked.

(2) The webs of emarginate primaries of hawks that have just been killed show well-defined "notches" where the edges of the interlocked webs have rested against one another. The facts determined by a long continued study of the formation of the notches are these:

(3) The notches formed by artificially interlocking the primaries are identical with those found after birds are killed and which are always present when the primaries are found interlocked.

(4) It requires from ten to twenty minutes to form even very slight notches artificially in the primaries of a freshly killed bird.

(5) When the notches are formed artificially by a strong pressure for several hours they are not as deep as those made by the natural interlocking of the primaries.

(6) The notches found in the primaries of freshly killed birds could not have been formed accidentally during the time between when the birds were shot and when they were examined (often less than 30 seconds), but were the results of a pressure due to the interlocking of the primaries acting either constantly or intermittently for two or three or more hours directly previous to the time when the birds were killed.

(7) The interlocking of the primaries as an auxiliary mechanism of flight appears to be advantageous for three reasons:

(a) To make the end of the wing, or that part formed by the primaries, more rigid when the wing is employed as an aeroplane in coasting flight.

(b) To produce a curvature of the wing which gives to the bird better control in the air.

(c) To keep the primaries partly extended without muscular exertion on the part of the bird; otherwise the air pressure produced by the motion of the bird acting against the primaries would tend to close them, unless the bird was continually exerting muscular force to keep them extended.

Confirmatory Observation in Japan.

After this paper had been submitted for publication, a letter on the subject appeared in *Science*,* written by Professor Bashford Dean describing an observation recently made by him in Japan. The facts of the observation were stated with careful detail, but only a small portion of the letter is here quoted.

"It so happened that we were coming up the narrow canal from Sakai to Matsue in the face of a strong wind, so strong, indeed, that our small steamer labored to make headway against it. At one point we disturbed a kite, *Milvus melanotus*—a very common bird, by the way, along Japanese waterways—which rose slowly in the face of the wind and after making several circles followed the margin of the canal, flying and soaring, almost opposite the boat and making about equal headway." . . . . . "For several minutes the hawk thus flew alongside of the boat, with quite regular periods of flapping and soaring; then, suddenly shifting its course, it circled out, soaring, passing over my head at a distance of about twenty feet. I could then see plainly that the primaries

* Sci. xxii, No. 564, Oct. 20th, 1905.

of one wing (right) were interlocked—the condition of the other wing I had not time to observe."

"My conclusion, therefore, is that the interlocking of the primaries of the hawks takes place, as Mr Trowbridge has shown, under the conditions of soaring in the face of a strong wind." Written from Rinkai Jikenjo, Misaki-Miura, Japan, September 3, 1905.

This confirmatory observation of Professor Dean's was apparently made under the most favorable conditions. The observer and the hawk were both moving for a part of the time at nearly the same velocity; therefore they were approximately stationary with respect to each other, and hence the bird must have appeared almost like a still object and the observation made with certainty.

The observations presented in this paper have shown that when hawks are killed in certain types of flight a large percentage of the emarginate primaries of their wings are found interlocked, and it has been proven that these feathers were interlocked for several hours previous to the moment when the hawks were killed; therefore the principle of the interlocking of the emarginate primaries in flight has been conclusively demonstrated.

Phoenix Physical Laboratory, Columbia University.
New York, September, 1905.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Determination of Nitrous and Nitric Acids.*—Weisenheimer and Heim describe a convenient method for the gasometric determination of either or both of these acids. The operation is carried out with a flask of 50^{cc} capacity, in which the slightly alkaline solution of the substance (containing ·1 to ·2 g. of nitrite) is placed. Carbon dioxide is led in from a Kipp's generator through a tube reaching below the liquid in the flask, and a delivery tube is attached which ends in a turned-up point in a trough containing 12 per cent sodium hydroxide, in such a manner that an eudiometer filled with the sodium hydroxide solution may be placed over the outlet. A funnel tube provided with a pinch-cock is placed in the third hole of the rubber stopper of the flask. The stem of this funnel tube is narrowed at the end and it is filled with water up to the funnel at the beginning of the operation. The apparatus is first freed from air by passing carbon dioxide through it, then 10 or 15^{cc} of a five per cent solution of potassium iodide are introduced, and then, slowly, the same amount of dilute hydrochloric acid. All the nitrous acid is thus converted into nitric oxide according to the equation

$$HNO_2 + HI = NO + I + H_2O.$$

The liquid is slowly raised to the boiling-point and the gas is swept over into the eudiometer by the stream of carbon dioxide, and is measured. When nitric acid is to be determined, a newly filled eudiometer is placed over the delivery tube, 10 or 20^{cc} of a concentrated solution of ferrous chloride in strong hydrochloric acid are introduced, and the gas formed according to the equation

$$HNO_3 + 3FeCl_2 + 3HCl = NO + 3FeCl_3 + 2H_2O$$

is collected and measured as before. Test analyses with nitrites and nitrates alone, and with mixtures of both, gave very satisfactory results. The method has the advantages of being rapid and in furnishing direct determinations of both acids in a single sample of substance.—*Berichte*, xxxviii, 3834. H. L. W.

2. *The Modifications of Antimony*—Stock and Siebert have found that, like arsenic, antimony exists in a yellow, a black, and a metallic gray modification. The last is the most stable form, and the only one heretofore mentioned in chemical literature. The black modification may be obtained by heating the yellow form to temperatures above −90°, by the action of oxygen upon liquid antimony hydride above −90°, and also by the sudden cooling of the vapor of ordinary antimony. Its specific gravity is 5·3, while that of the ordinary metal is 6·7. It is chemically active, often igniting when exposed to the air. It is changed into metallic antimony by heating, the change being instantaneous at 400°. The authors consider the black precipitates pro-

duced by the action of certain reducing metals upon antimony solutions as mixtures of black and metallic antimony. The preparation of yellow antimony is difficult, since it rapidly blackens at temperatnres above −90°. It is formed in small quantities by the action of oxygen upon SbH_3 at −90° or −91°, just above its freezing point. It is formed also by the reaction of chlorine and antimony hydride when dissolved in liquid ethane at −100°. The authors call attention to the interesting fact that while antimony, arsenic, and phosphorus have similar allotropic modifications, the stable form at ordinary temperatures is the metallic one with antimony, the black one with arsenic, and the yellow one (in absence of light) with phosphorus.—*Berichte*, xxxviii, 3837.

H. L. W.

3. *Quantitative Determination of Bismuth.*—Two articles have been recently published in which the determination of bismuth as the phosphate, $BiPO_4$, is recommended. Staehler and Schaffenberg find that the metal may be completely precipitated by adding tribasic sodium phosphate to the nitric acid or hydrochloric acid solution until the stronger acid has been replaced by phosphoric acid, since in the latter the precipitate is entirely insoluble. The precipitation is made at a boiling temperature by the addition of boiling ten per cent sodium phosphate solution. If the liquid becomes alkaline, it should be acidified with a little nitric acid. After boiling a short time the precipitate settles well, and then, while the liquid is hot, the substance is collected on a Gooch filter, and washed with a one per cent solution of nitric acid to which a trace of ammonium nitrate is added. After drying, the precipitate is ignited for ten minutes over a large Bunsen burner, and is then weighed. Test analyses gave excellent results, and it was shown that bismuth can thus be separated from copper, cadmium, mercury, and silver, but not from lead, since lead phosphate is but slightly soluble in phosphoric acid.

H. Salkowski, for determining bismuth as phosphate, recommends operating in a weak nitric acid solution, in which case the separation from Cu, Cd, Hg, Ag, Pb, Fe, Mn, Co, Ni, Zn, Cr, and Al may be effected with good, or in some cases with only satisfactory results. In this case, where a strong acid is present, hydrochloric acid and other chlorides must be absent. Attention is called to the fact that the almost complete insolubility of bismuth phosphate in weak nitric acid affords a very satisfactory method for the qualitative detection of bismuth.—*Berichte*, xxxviii, 3862 and 3943.

H. L. W.

4. *The Distillation of Gold.*—Moissan finds that gold can be readily distilled in the electric furnace, that its boiling-point is higher than that of copper, but lower than that of calcium oxide. When the vapor is condensed on a cold surface, the metal is found in the filiform condition, or in very small microscopic crystals. When alloys of gold and copper, or of gold and tin, are distilled, the copper and the tin distill more rapidly than the gold.

Moreover, in distilling an alloy of gold and tin, when the mixed vapors come in contact with air the tin is oxidized and the gold condenses in the finely divided condition corresponding to the "purple of Cassius." Similar purple products are formed also with other oxides, such as silica, zirconia, lime, magnesia, and alumina.—*Comptes Rendus*, cxli, 977. H. L. W.

5. *Fluoride of Bromine.*—Although Moissan had noticed that fluorine reacts with bromine very vigorously, the product of the reaction was not isolated by him. LEBEAU has now prepared the compound and has found that it is a colorless, fuming liquid corresponding to the formula BrF_3. Its vapor is very irritating, attacking the skin violently. It solidifies at about 4° to a colorless, crystalline solid. The compound possesses great chemical activity, reacting violently with water, and attacking many other substances similarly to free fluorine.—*Comptes Rendus*, cxli, 1018. H. L. W.

6. *On some Properties of the α-Rays from Radium.*—Prof. E. RUTHERFURD thus summarizes his recent investigation of this subject.

(1) The rays from radium in radio-active equilibrium are complex, and consist of α particles projected with different velocities.

(2) The α particles decrease in velocity in passing through air and through aluminium.

(3) The absence of increased deflection of the rays from a thick layer of radium, after passing through aluminium, observed by M. Becquerel, is a necessary consequence of the complexity of the rays.

(4) The decreasing path of the rays in air, observed by Becquerel, is also a necessary consequence of the complexity of the rays.

(5) There is evidence of a distinct scattering of the rays from radium C in their passage through air.—*Phil. Mag.*, Jan. 1906, pp. 166–176. J. T.

7. *Emission Spectrum of the Auer burner.*—H. RUBENS has measured the amount of energy given out by the so-called Degeas mantle which is composed of 99·2 per cent thorium oxide (ThO_2) and 0·8 per cent cerium oxide (Ce_2O_3). The method of measurement was substantially that described in Wied. Ann., lx, p. 737, 1897. The measurements were taken between wave lengths $\lambda = 0$, 45μ and $\lambda \pm 18\mu$. Curves of energy are given for the Auer burner in question, for the ordinary Bunsen burner and with a mantle covered with a thin layer of iron oxide. One obtains the latter by dipping the Auer burner in ink and then raising to a glow in the Bunsen burner. The mantel shows then in the flame mantel of the burner a red glow. The curves show that the mantel of the Auer burner is transparent for the rays of the Bunsen burner. They also show that the Auer burner radiations depart largely from the maxima of the Bunsen burner. Rubens believes that the cerium oxide plays a role in the burner similar to that of a sensitizer on the photographic plate in that it brings

forth an absorption region at a desired place without influencing the remaining spectral region. If another coloring substance could be found which added to the thorium mantel could blacken not only the short waves of the visible spectrum but also the yellow and red without disturbing greatly the ultra-red, the light working of the burner would be increased three times.—*Ann. der Physik*, No. 14, 1905, pp. 725–738. J. T.

8. *Afterglow produced by Lightning Discharges.*—E. Touchet (Compt. Rend., cxl, p. 1031, 1905) accounts for this by the supposition of an after-heating of the air. K. E. F. Schmidt (Elektrotechn. Zeitschrift, xxvi, p. 903, 1905) believes that it is a phosphorescent effect. B. Walter gives his reasons for supposing that it is due to an after-discharge of electricity along the first path of the original discharge.—*Ann. der Physik*, No. 14, 1905, pp. 863–866. J. T.

9. *Specific Heat of Superheated Steam.* — Regnault in his investigation on this subject used a water calorimeter at the temperature of the room. This method had the disadvantage that the steam condensed in the calorimeter. To avoid the resulting errors Regnault let steam at 128° and afterwards at 217° stream through the apparatus. L. Rubens and F. Henning use paraffin oil instead of water above 100° and thus avoid the condensation of the steam, and proceed as with non-condensing gases.

They obtain the result $C_\theta = 0{,}4410\ (1 + 0{,}00014_8\theta)$.—*Ann. der Physik*, No. 14, 1905, pp. 739–756. J. T.

10. *Use of the Microphone Contact for Telegraphic Relays, and for Detection of Weak Currents.*—It has occurred to many inventors that a relay might result from simply placing a microphone contact against the vibrating disc of a telephone. It was soon realized that the excursions of such a disc were too small to actuate efficiently such a microphonic contact; moreover the pressure of the contact on the disc interfered with the vibration of such a disc. Chr. Jensen and H. Sieveking have taken up the general subject of microphonic contacts with the view of using them in some form of telephonic relay. In order to shun disturbing vibrations the microphonic contact was placed on a Julius suspension consisting of a heavy board or table hung from the ceiling with the usual arrangement of supporting wires. They found this suspension very useful. No mention, however, is made of the singing of microphonic contacts; a trouble which is very difficult to overcome in the practical use of any microphonic contact. Possibly the currents employed by these investigators were too feeble to cause this singing. The paper contains a great many measurements of microphonic resistances and concludes with the following questions which were suggested by the investigation.

(1) What sensitiveness must one desire in order to obtain a practical working telegraphic relay?

(2) In avoiding shaking or other disturbances within what limits is it safe to work without the necessity of too delicate adjustments?

(3) What pressure is it best to select?

(4) What electromotive force at the contact should one employ?

The authors did not succeed in supplanting the galvanometer by a microphonic contact for the detection of very feeble currents.—*Ann. der Physik*, No. 14, 1905, pp. 695–724. J. T.

11. *Mathematical and Physical Papers;* by Sir GEORGE GABRIEL STOKES, Bart. Vol. V, pp. xxv + 370 (Cambridge University Press).—This is the final volume of the collection and covers the period from 1876 to 1903. It is well known that, during these years and, in fact, for some time prior to 1876, Stokes spent much labor upon his duties as secretary of the Royal Society and as a member of its publication committee. These duties were so conscientiously performed that (in the opinion of those who knew him) they interfered greatly with his own work. But the service to science which he thus indirectly rendered by aiding, criticizing, and suggesting extensions of the work of others, must have been very great. Some idea of this service may be obtained from the present volume, which is largely made up of notes and explanations appended to papers by other authors in the publications of the Royal Society. One hitherto unpublished paper upon Water Waves (written in 1880) is included, as is also the Wilde Lecture on the nature of Röntgen rays, in which the accepted theory of these rays was first proposed. A very interesting feature of the volume is the series of examination papers which Stokes prepared, from time to time, for the Mathematical Tripos and for the Smith's Prize Examination at Cambridge.

In the preface, Prof. Larmor promises a further volume "of biographical character, to be occupied in part by a selection from Sir George Stokes' voluminous scientific correspondence, including some unpublished manuscript material"; this will be looked for with much interest and it is to be hoped that nothing will interfere with its early publication. H. A. B.

12. *Lehrbuch der Physik;* von O. D. CHWOLSON. Band III. Deutsch von E. Berg. Pp. xi + 988. Braunschweig (F. Vieweg und Sohn).—The first two volumes of this German translation of the Russian text-book of Prof. Chwolson have been noticed in previous numbers of this Journal. The present volume deals with the theory of heat and has the same admirable qualities of clearness, completeness and perspective which are so noticeable in the earlier volumes. H. A. B.

13. *The Polariscope in the Chemical Laboratory. An Introduction to Polarimetry and Related Methods;* by GEO. WM. ROLFE, A.M., Instructor in Sugar Analysis in the Mass. Institute of Technology, pp. 320, 8vo. New York, 1905. (Macmillan Co.)—It has happened not infrequently in the past that American men of science, when impelled by one or another motive to prepare elementary text-books, have produced works decidedly superior to any analogous publications that had appeared previ-

ously in Europe. This result may perhaps depend primarily on the national virtue vaunted by Matthew Arnold, that "in matters within their range most Americans see straight and see clear," but is doubtless influenced also by an altruistic sentiment acting to help forward the cause of education and of national well-being such as was illustrated very remarkably long ago by the career of Noah Webster as set forth by Horace Scudder in his biography. The fact that such books are usually written without any hope of pecuniary gain throws them in a sense into the category of scientific memoirs and imparts a note of eclecticism, open-mindedness and fair-mindedness not to be looked for in the ordinary productions of Grub St. The book of Mr. Rolfe is noteworthy as a successful effort to elucidate and explain to beginners and even to the intelligent workman a form of scientific apparatus which is not infrequently held to be innately complex and difficult of comprehension. He has done this simply and clearly, and his descriptions cannot fail to be understood by all persons occupied with the business of testing and manufacturing sugars. The book will be appreciated also by those chemists and students of chemistry who wish to keep in touch with the progress of knowledge in the great field of saccharine matters and the related carbohydrates. F. H. S.

II. Geology and Mineralogy.

1. *Status of the Mesozoic Floras of the United States* (Second Paper); by Lester F. Ward, with the collaboration of William M. Fontaine, Arthur Bibbins, and G. R. Wieland. Part I, Text, 616 pp.; Part II, Plates I–CXIX. Monograph XLVIII, U. S. Geol. Survey. (Washington, 1905.)—The extensive and sumptuously illustrated work before us forms the seventh paleobotanic monograph published by the United States Geological Survey. It, however, more immediately follows Part II of the 19th annual report, On the Cretaceous Formations of the Black Hills as indicated by the Fossil Plants, and Part II of the 20th annual report, On the Status of the Mesozoic Floras of the United States,—both of which are of monographic proportions. The monographs of the survey solely on fossil plants are therefore now virtually ten in number.

The subjects of Monograph XLVIII, being mostly in continuation of previous work, occupy a wide range, chiefly as follows: The older Mesozoic of Arizona; the Jurassic of Oregon with the description of numerous ferns and many handsome cycad and ginkgo leaves with other conifers; various minor Jurassic-Cretaceous floræ from Cape Lisburne, Alaska, from Montana, and from California; the description of many additional cycadean trunks from the Freezout Hills of Carbon County, Wyoming, to the illustration of which 18 handsome plates are devoted; the flora of the Shasta formation of California and Oregon; further plants from the Kootanie of Montana, and the Lakota of South

Dakota ; an exhaustive description of the occurrence and macroscopic characters of the cycadeoidean trunks from the lower members of the Potomac group of Maryland, illustrated by many plates ; the description of various additional plants or specimens from the Potomac group of both Virginia and Maryland with various correlations and a discussion of the age of the beds.

The study of the Maryland and Wyoming cycadean trunks is by Professor Ward. The most of the descriptions of floræ are by Professor Fontaine. Mr. Bibbins contributes a paper on the Potomac group and the occurrence of the cycadean trunks therein, together with a splendid triple-plate map (Plate LXXX), showing the areal distribution of the formations of the Potomac group in Maryland, on which are indicated all of the known plant and cycadean trunk localities. Mr. Wieland's contributions to the volume include the discovery of the leaves of the Wyoming cycad trunks, with some account of their structure, and two papers on the stratigraphy and paleontology of the Black Hills rim, including a description of the leaves of the Lakotan quasi-cycad *Nilssonia nigricollensis*, strikingly like some of the forms of the Oregon Jurassic described by Fontaine.

Most interesting is the beautiful cycadean trunk from the Grapevine Valley of Colusa County, California, described by Professor Ward. This fossil is from the lower Chico or Horsetown beds, the strata in which it occurs doubtless being of much the same age as those yielding the numerous cycadean trunks in Maryland and South Dakota. The most interesting feature displayed by the trunk is the presence of a peduncle in the axil of every leaf-base of the lateral trunk surface. This extraordinarily prolific growth of axillary fruits likewise characterizes the fine type *Cycadeoidea nigra* from Boulder, Colorado, but is not found in equal degree in any other cycadean specimens.

For the first time the Cycad trunks from Maryland are adequately illustrated by numerous and beautiful plates, and Professor Ward also adds many views of additional trunks and finely conserved fragments from the Freezout Hills of Wyoming. While holding the illustration and descriptions given by Professor Ward as in the main most effective, necessary and admirable, the reviewer nevertheless feels called upon to say that he does not find from his own anatomical and structural studies that there is any such great specific variation as is ascribed to these cycads. Macroscopic leaf-base and armor characters may serve to distinguish certain occasional and unique specimens within specific limits; but as soon as one comes to deal with a large number of trunks, so many transitions in preservation and structure appear that the method fails of accuracy.

The study of the additional materials from the Potomac series of Virginia and Maryland shows a similarity of floral change in these beds of both states. It also appears that while important floral changes of the Potomac group are evident in the Raritan, little change in vegetation occurred during the Patuxent

and Arundel, doubtfully referred by Bibbins to Upper Jurassic and ascribed to the Lower Cretaceous by Professors Ward and Fontaine. Neither of the latter now hesitate to regard the flora of the Potomac as essentially Wealden and Lower Cretaceous, on the basis that the Wealden is the non-marine equivalent of the Neocomian, this being of course the most interesting geologic question dealt with by the volume. As Marsh held the Potomac to be Jurassic on the basis of its pre-Neocomian equivalency, there is of course no hiatus in the observations of those who have dealt with the upper boundaries of the Jurassic—always so uncertain because in both Europe and America the marine Jura is followed by the formation of fresh- to brackish-water beds most difficult to divide, though containing the most striking fossils. The reviewer had the pleasure of hearing Professor Marsh defend his hypothesis many times, and perhaps mainly because of that fact finds some difficulty in regarding the question as fully and finally closed. It does appear, however, that, as Professors Ward and Fontaine insist, the evidence that the Wealden is an unconformable transition series has much increased. It is also to be urged that the direct evidence of marine Jurassic superposition, as in the still doubtful cases like the Glen Rose beds of the Trinity group in Texas, must still be awaited with much interest; that the origins of animal and plant forms are always being traced further and further back; and finally, that it is a very significant fact that the dicotyls creep in as if by stealth in both the Arundel (*Rogersia*), and near the Minnewaste limestone in the Black Hills (*Sapindopsis*).

This appearance of new species with a strong invasive power may well mark profound physical changes within Potomac time, though such may be locally difficult to determine. G. R. W.

2. *Geology and Paleontology of the Judith River Beds;* by T. W. Stanton and J. B. Hatcher. Bull. 257, U. S. Geol. Surv., 1905, pp. 174, pls. 19.—During the year 1902, there was published a series of short, but interesting discussions between Osborn, Hatcher and Stanton, showing considerable difference of opinion regarding the position of the Judith River beds and their correlation with the Belly River beds of Canada. These difficulties were worked out satisfactorily in the field during 1903, in northern and central Montana and adjacent areas of Canada. The principal conclusions of Stanton and Hatcher are as follows:

"(1) The Judith River beds are distinctly older than the Laramie, being separated from the latter by at least several hundred feet of marine shales identical in their faunal and lithologic features with the Pierre to which we have given the local name Bearpaw shales, from the Bearpaw Mountains about which they are well exposed.

"(2) The Belly River beds of Canada are identical with the Judith River beds of Montana. The name Judith River beds, having priority, should be the accepted name for this formation and the terms Belly River and Fish Creek should be dropped.

"(3) The marine sandstones and shales immediately underlying the Judith River beds do not represent either the Benton, as some Canadian geologists have supposed, or the Fox Hills and upper Pierre, as most geologists of the United States who have examined them have believed, but they constitute a distinct horizon within the Montana group which we have called the Claggett formation, from old Fort Claggett at the mouth of Judith River, near which they are well developed.

"(4) The Eagle formation, from its stratigraphic position and faunal relations, marks the base of the Montana group in this region.

"(5) The Bearpaw shales, the Judith River beds, the Claggett and the Eagle formations all belong to the Montana group, and together probably form the equivalent of the Pierre as that term is generally understood, though the possibility is recognized that in the typical area the Pierre may have more restricted limits.

"(6) Faunas similar to that of the Fox Hills sandstone have a great vertical range and are likely to be found at any horizon within the Montana group where a littoral or shallow-water facies is developed. The use of the term Fox Hills as a formation or horizon name outside of the original area in South Dakota is therefore of doubtful propriety, as experience has shown."

The vertebrate fauna is described by Hatcher. "A considerable number of genera and species pertaining to all five of the known classes of vertebrates have been described. Unfortunately these genera and species are for the most part based on exceedingly fragmentary and unsatisfactory material." Of fishes there are 8 species; of tailed Batrachia, 5; Plesiosauria, 3; Chelonia, 14; Rhynchocephalia, 4; Crocodilia, 2; Dinosauria, 37; birds, 1; mammals, 2. "When considered in its entirety, the vertebrate fauna of these beds is remarkably similar to, though distinctly more primitive than, that of the Laramie. Almost or quite all of the Laramie types of vertebrates are present, though, as a rule, they are represented by smaller and more primitive forms. The similarity between this fauna and that of the Laramie contrasts strongly with the great dissimilarity between the vertebrates of the Judith River and those of the Atlantosaurus beds, the next older fresh-water horizon in this region."

Of invertebrates, Stanton notes 35 species of Pelecypods, 30 Gastropoda, 1 Placenticeras, and 1 cockroach. "The species enumerated . . . fall into the three general categories of marine, brackish-water, and fresh-water forms, the latter including a few more or less doubtful land shells." The brackish-water fauna contains *Ostrea*, *Mytilus*, *Modiola*, *Anomia*, *Corbicula*, *Corbula*, *Panopæa*, *Rhytophorus*, and *Goniobasis*. As a rule, the fresh-water forms are found in distinct beds associated with land Mollusca and land vertebrates. "It is evident that after the deposition of the Claggett formation a considerable area in north central Montana and in Alberta and Assiniboia emerged from the sea and became the habitat of land and fresh-water animals.

Since there was no obvious break in the sedimentation, it is probable that the larger part of the area was covered by low-lying swamps and lagoons. For some time there were slight oscillations that occasionally for brief intervals brought large parts of the area down to sea-level and gave the lagoons sufficient connection with the ocean to allow the growth of oysters and other brackish-water forms over areas that had been occupied by fresh waters. Then for a longer period, during which 300 or 400 feet of sediments were formed, there was no connection with marine waters, though it is not probable that the area was ever very many feet above tide. During this epoch the general upward movement was reversed, and when the subsidence progressed more rapidly than deposition connection with the sea was soon again established, bringing in, first, brackish waters with their oyster beds, over nearly the entire area, with probably local bays and straits having more open and direct oceanic connections, such as is indicated by the occurrence of marine fossils in the Judith River on Cow Creek. Finally marine conditions were fully established over the entire area, so far as known, and continued during the deposition of the Bearpaw shales."

The fossil plants of the Judith River beds are described by Knowlton. There are 28 species. Of these, 8 are conifers, "and when the actual number of individual specimens is considered it is safe to say that fully nine-tenths belong to these species."

"It appears that the flora of the Judith River beds that has thus far come to light shows very little affinity with the true Laramie or the Fort Union, but does exhibit an undoubted relationship with that of the Dakota group or with the Cenomanian and Senonian of the Old World, or, in broad terms, with the lower and middle portions of the Upper Cretaceous." C. S.

3. *Paleontology of the Malone Jurassic Formation of Texas;* by F. W. CRAGIN. Bull. 266, U. S. Geol. Surv., 1905, pp. 172, pls. 1–29.—It is not often that American Paleontology is enriched by a work describing a marine Jurassic fauna, and this bulletin is therefore all the more desirable. The region from which the fauna was gathered is about Malone Mountain, or about 75 miles southeast of El Paso, in Texas. On the basis of the ammonites, this fauna shows the closest affinities with that of the Tithonian of Europe. The nearest relations of American localities with that of Malone are in Mexico, having been described by Castillo and Aguilera. The relation of the Jurassic with the overlying Lower Cretaceous could not be made out, because no continuous section connecting the two systems was seen. An important feature of this work is a chapter of eleven pages by Stanton, entitled "Stratigraphic notes on Malone Mountain and the surrounding region, near Sierra Blanca, Tex."

The fauna consists of: Corals, 1 (new); Echinoidea, 2 undetermined forms; Vermes, 3; Bryozoa 1 (new); Pelecypoda 56 (40 new); Gastropoda, 18 (17 new); Cephalopoda 10 (5 new). No land vertebrates were seen, only fragments of fishes and swimming reptiles. C. S.

4. *The Copper Deposits of Missouri;* by H. F. BAIN and E. O. ULRICH. U. S. Geol. Surv., Bull. No. 267, 1905, pp. 52.—"Copper is found only in the southern part of Missouri, within the region broadly known as the Ozark uplift." The annual output has thus far been small; for 1903 it was $30,210.

The stratigraphic sequence and the extensive synonymy of the Ozark rocks are worked out in detail by Ulrich, and as it will be of service throughout the Mississippi Valley, his table of formations is presented herewith:

System.	Series.		Formation.	Thickness.
Ordovician	Saratogan and Lower Ordovician	Potosi or Yellville group	Joachim limestone	0–150
			St. Peter ("Crystal City") sandstone	0–200
			Jefferson City limestone	50–250
			Roubidoux formation	70–225+
			Gasconade limestone	450–650
Cambrian		True Saratogan	Elvins formation	0–120
		Acadian	Bonneterre limestone	-----
			La Motte sandstone	0–300
Archean granites and porphyries				

C. S.

5. *Developmental Stages in the Lagenidae;* by JOSEPH A. CUSHMAN. Amer. Nat., Aug., 1905, pp. 537–553.—This readable short paper for the first time applies Hyatt's Principles of development to the unicellular animals. The growth stages in compound forms are easily determined, and phylogenies of considerable importance are established. The simplest form in the family is *Lagena*, and the *Lagena*-stage is present in *Nodosaria*, *Marginulina*, *Dimorphina*, *Polymorphina*, and *Cristellaria*. Old age characters, uncoiling, and the development of spinose or "wild growths" are also clearly shown. The paper gives a remarkably clear exposition of how Hyatt's Principles may be applied to the Foraminifera. C. S.

6. *Revised Nomenclature of the Ohio Geological Formations;* by CHARLES S. PROSSER. Geol. Surv. Ohio, 4th ser., Bull. 7, 1905, pp. i–xv, 1–36.—As the title of this paper indicates, it revises the names applied to the geological formations of Ohio, in accordance with modern usage. It is a revision and elaboration of a similar paper published by the same author in the Journal of Geology, Oct., 1903, pp. 519–547.

7. *Mesozoic Section on Cook Inlet and Alaska Peninsula;* by T. W. STANTON and G. C. MARTIN. Bull. Geol. Soc. America, June, 1905, pp. 391–410, pls. 67–70.—This is a very important paper describing in some detail the Upper Triassic (2000 feet), Lower Jurassic (1000), Middle Jurassic (1500–2500), Upper Cretaceous (1000), and Tertiary (2000) strata of the Cook Inlet region. The writers also illustrate a very interesting local unconformity, which they were able to trace for about a quarter of a mile. "The fact that the same fauna is found both above and below this unconformity is evidence that the erosion interval was geologically brief, and it probably did not affect a wide area."

8. *New York State Museum; Report of the Director, 1904.* JOHN M. CLARKE. 1905, pp. 1–146.—This is the report of the Director of the Science Division of the Education Department, the State Museum, and the State Geologist and Paleontologist, for the year ending September, 1904. The report states what has been done during the year, and the work now in hand.

9. *The Geology of Miller County;* by S. H. BALL and A. F. SMITH.—Mo. Bureau Geol. and Mines, I, sec. ser., 1903, pp. i–xvi, 1–207, many plates and a geological map.—Describes the geology of the Cambrian, Ordovician, Mississippian, Pennsylvanian, and Pleistocene formations of the county.

10. *The Quarrying Industry of Missouri;* by E. R. BUCKLEY and H. A. BUEHLER. Ibid., II, sec. ser., 1904, pp. i–xv, 1–371, many plates and a geological map.

11. *The Geology of Moniteau County;* by F. B. VAN HORN and E. R. BUCKLEY. Ibid. III, sec. ser., probably 1905, pp. i–viii, 1–104, many plates and a geological map.—There is no date on the title page of this book, it being replaced by the stamp of the "Typographical Union." It is to be hoped that this practice will be relegated to the rear, as the date of a book is worth far more to its users than the fact that the work was set up by a given typographical union.

In this volume, the geology of the Cambrian, Ordovician, Devonian, Mississippian, Pennsylvanian, and Pleistocene formations of the county are described.

12. *Note on the use of Buena Vista as the name of a geological terrain;* by CHARLES S. PROSSER. (Communicated.)—In the December (1905) number of this Journal, Professor H. D. Campbell proposes the name "Buena Vista shale," derived from a town of that name in Virginia, for the upper formation of the Cambrian system in the middle portion of the Valley of Virginia

(vol. xx, pp. 445, 446). So far as the writer is aware, Buena Vista as the name of a geological division was first used by Dr. Edward Orton in his report of Pike county, Ohio, and published in 1874. The term was applied to a subdivision of the Subcarboniferous (Mississippian) rocks of southern Ohio, and Dr. Orton's statement was as follows: "This subdivision has a definite base, viz., the upper surface of the Waverly black slate [now known as the Sunbury shale]; but there is no characteristic stratum that constitutes a convenient superior limit. As the most valuable of the building rock, however, that is furnished by this part of the series in southern Ohio occurs within fifty feet of the slate, these fifty feet next above the slate may be somewhat arbitrarily taken as a subdivision. It may be designated as the Buena Vista section—the name being derived from a locality on the Ohio River that furnishes a large amount of stone of unequaled quality." (Rept. Geol. Surv. Ohio, vol. ii, Pt. I, p. 626.) This name was revived, the upper limit of the terrain defined, and applied to the lower member of the Cuyahoga formation in southern and central Ohio by the writer in December, 1904 (Amer. Geol., vol. xxxiv, f.n. on pp. 341, 342). In view of the above facts it does not appear to the writer that Buena Vista is available for the name of a Cambrian formation of Virginia.

13. *The Configuration of the Rock Floor of Greater New York;* by WILLIAM HERBERT HOBBS. 1905. Bull. No. 270, U. S. G. S. Pp. 96, Plates V, figs. 6.—The present is an especially favorable time to study in detail the structure of the rock floor of Greater New York by means of the bore holes and excavations which have been made in the course of engineering operations. This information if not now collected would be ultimately largely lost and Professor Hobbs, perceiving this some years ago, has collected a large amount of geological information which will be of the highest importance to engineers engaged in construction work. The details also have bearings, as Professor Hobbs points out, upon structural problems in the geology of the region. J. B.

14. *Formation of Phenocrysts in Igneous Rocks.*—In his opening address before the Geological Section of the British Association for the Advancement of Science at the meeting in South Africa, Prof. H. A. MIERS, president of the section, alluded to a number of important problems in geology whose elucidation is greatly aided by experimental research. Chief among these is the difficult question of the differentiation of igneous magmas and the origin of igneous rocks. After mentioning the results attained by different workers in this field the speaker gave some of his own results obtained in the study of the cooling and crystallization of saturated solutions which tend to throw light on rock textures.

Ostwald had previously shown that a saturated solution can exist in such a condition that crystallization may take place spontaneously or be readily induced by shaking, etc.; this is termed the *labile* state. On the other hand, the solution may be in such a

condition that no amount of stirring or shaking or introduction of foreign substances can make the solution crystallize and it appears that this can only be done by the introduction of a crystal, or the part of one, of the dissolved substance. This latter is called the *metastable* state.

Prof. Miers has made experiments to ascertain the exact limits between these two states in a given solution, determining the changing concentration by an optical method, and the temperature at which the change into the labile state occurs. Thus it was found that in a solution of sodium nitrate containing 48 per cent of the salt, if dust (containing assumably submicroscopic particles of $NaNO_3$ or "germs") be not excluded, crystals make their appearance on the surface of the liquid, grow, and sink, but although they may be actively stirred about no new ones form and the liquid remains in the metastable state till a temperature somewhat below 16° is reached, when the labile region is entered and a cloud of new crystals make their appearance. Thus in a cooling supersaturated solution from which germs have not been excluded there are two periods of growth; one in which a comparatively small number of isolated crystals are growing regularly and a subsequent period in which a shower of small crystals is produced. If the rate of cooling is slow enough or the stirring violent enough to keep the liquid in the metastable condition there will be no second period or sudden production of small crystals. These events were found to take place in all of the solutions studied and the same process is suggested as an explanation of the porphyritic texture found in igneous rocks; "in a silicate magma in all probability the temperature is sufficiently high to be that of the metastable condition, the rate of cooling sufficiently slow to keep the liquid in that condition for a considerable time and the viscosity sufficiently great to prevent the growing crystals from sinking at once; we have therefore all the conditions favorable for the growth of *porphyritic* crystals; these must have generally originated throughout the liquid as spontaneous nuclei if the magma entered the labile state, or may have been started by inoculation or cooling at the margin if the magma as a whole remained in the metastable state. In the latter case suppose that further somewhat sudden cooling brings the magma to the labile condition, then there will be a sudden and spontaneous second growth of nuclei which will not be able to attain the dimensions of the porphyritic crystals; we have here all the conditions necessary for a *second generation* of one of the constituents of the rocks." L. V. P.

15. *Beiträge zur chemischen Petrographie;* von A. Osann, *II Teil, Analysen der Eruptivgesteine aus den Jahren, 1884–1900.* Pp. 266, 8vo. (Stuttgart, 1905.)—This work is in fact a continuation of that of Roth, whose well-known Tabellen proved for many years of such value to petrographers. It will be used chiefly by Europeans, as in this country it is replaced by Washington's great work, but since in the latter the analyses are

arranged according to the new quantitative system, the book referred to will also be of service, as in it they are arranged according to the classification of Rosenbusch and thus supplement his well-known work. The book has been made up in a way that makes it very convenient for reference and its whole arrangement evinces both industry and careful compiling.

L. V. P.

16. *Beiträge zur Petrographie des westlichen Nord-Grönland;* von M. Belowsky. Zeitschr. d. deutsch. Geol. Gesellsch. lviii, pp. 15–90, 1905.—The material upon which this investigation is based was collected and brought back by Drygalski in his expedition to the west coast of Greenland in the years 1891–1893. It consists chiefly of pebbles from glacial moraines. As a result of the work the author concludes that northwest Greenland consists chiefly of crystalline schists referred to the Archean and of Cretaceous strata penetrated by basalt.

The crystalline schists are gray mica and hornblende gneisses with inclusions of hornblende rocks of various kinds and cut by granite intrusions. All these gneisses are supposed to be of eruptive origin. One of them is interesting from the fact that it contains a blue alkali hornblende referred to astochite, the rock thus representing among the gneisses, the alkali series of the igneous families. The hornblende included masses are referred to altered peridotites.

The pebbles in the moranial material show that not only crystalline schists but rocks of higher horizons are covered by the inland ice. The later eruptive rocks which break through the Cretaceous are feldspar basalts. The author suggests that the petrographic characters of the Greenland gneisses allies them with those of the Scandinavian peninsula and that they may be of the same age.

L. V. P.

17. *Recherches géologiques et pétrographiques sur les Laccolithes Environs de Piatigorsk (Caucase du Nord)*; par Vera de Derwies. Pp. 84, 4°; 12 figs. and 3 plates (map). Geneva, 1905.—On the northern outslopes of the Caucasus lies a hilly area, celebrated for its mineral springs which have rendered it one of the health resorts of Russia. Several small towns, whose existence is largely due to the influx of patients desiring to avail themselves of the curative properties of these waters, have grown up in this region. The best known of these is Piatigorsk (Five Hills) connected by a branch with the main railway line to Vladikavkas and the Caucasus. The main topographic features of the area, through which the branch line runs to Piatigorsk, are a group of scattered hills which are formed by a number of laccoliths intruded into the Jurassic beds. As has been frequently found to be the case in western America they occur on the outer flank of the main mountain chain, where the sedimentary strata begin to be flexed by orogenic disturbance.

These laccoliths present every stage of erosive dissection from examples, in which the covering has not only been removed but

the igneous mass has been so deeply bitten into that only a remnant remains, to those where only at the top is a small portion of it revealed and finally the case where no igneous rock is seen but must be inferred from the structure and associations of the domed elevation. The igneous rocks composing these masses present several varieties of feldspar porphyry, quite similar to those found in the laccoliths of Colorado and Montana.

This region was visited and briefly studied in the autumn of 1897 by those geologists who took part in the excursion to the Caucasus of the VIIth International Congress at St. Petersburg and it afforded to the European members of the party an excellent and instructive example of geological phenomena which many of them had until then regarded as confined to America, and which hitherto they had not had an opportunity of seeing.

The area has now been studied and mapped by the author quoted above and the results of the work which have been carried out under the direction of Prof. Duparc of Geneva, are given in full, especially on the petrographic side. The rocks of the different occurrences have been analyzed and in the conclusion a number of deductions are drawn. This work will be of especial interest to many American geologists for its confirmation, in another part of the world, of the results of their studies of the phenomena of laccolithic intrusions. L. V. P.

18. *Physikalische Krystallographie und Einleitung in die krystallographische Kenntnis der wichtigsten Substanzen;* von P. Groth. Pp. 820, with 750 figures and 3 colored plates. Leipzig, 1905 (Wilhelm Engelmann).—It is interesting to compare the volume which has just appeared with its three predecessors published at intervals during the past thirty years. The increase in size from the 528 pages of the first edition (1876) to the present volume, one-half larger, is the most apparent change, but more important still is the development and expansion which the successive works show in the principles and their applications as they concern the topics embraced under Physical Crystallography. The author has a happy power of assimilating and making use of all that is most valuable and novel in the work of others, and at the same time his own independent investigations enable him not only to make important contributions of his own, but also to bring the whole into a compact and homogeneous system. The changes which the present edition exhibits most particularly are those concerned with the classification and mutual relations of the different physical properties. Something of this will appear from the classification given in the Introduction.

The physical characters of crystals are distinguished first as *scalar* and *vectorial.* The former are those which are independent of direction, as density, specific heat, etc., for crystals and all the properties of amorphous substances. The latter embrace those in which the direction is essential; further in regard to them, the term "bivectorial" is used for properties not acentric, that is, similar in opposite directions from a given point. The bivec-

torial physical characters are, further, classified into those of higher and lower symmetry. The former are called "ellipsoidal characters" because their numerical values for all possible directions are determined by at most three different values in directions at right angles, corresponding in general to the axes of an ellipsoid. Here belong, for example, the optical characters, according to which all crystals fall into five divisions. The bivectorial characters of lower symmetry embrace these concerned with elasticity and cohesion and the lowest grade of all is shown by those involved in the molecular growth and resulting structure of the crystal, where thirty-two classes are required to embrace all possible types. The discussion in succession of all the various characters, beginning with those involving light, is clear and complete. The subject of the molecular structure of crystals, from the theoretical side, is also clearly presented, and it is shown how the fundamental laws of rational indices and zones follow. The second half of the volume is devoted to the description of the successive systems, with the various classes falling under them and the special forms belonging to each. The methods employed in the investigation of crystals are treated in the last one hundred and fifty pages.

19. *Preliminary Notice of a New Meteorite from Texas;* by KENNETH S. HOWARD (Communicated).—A new aërolite from the Staked Plains of northwestern Texas has just been secured by Ward's Natural Science Establishment. It will be known as the Estacado, having fallen near the place of that name in 1882. The following results are taken from an unfinished analysis by Mr. John M. Davison:

Specific gravity 3·63. Metallic part 16·41 per cent. Stony part 83·59 per cent, of which 53·61 per cent is insoluble in HCl and 29·98 per cent is soluble. The analysis of the metallic portion calculated to 100 per cent is

Fe	89·45%
Ni	9·99
Co	·56
P	trace
Cu	trace
	100%

A complete account will be published shortly.

20. *Mineralogical Survey of Ceylon, Report for 1904;* by A. K. COOMARASWAMY, Director. Pp. 21 with map and 3 plates.—This Report gives much valuable information in regard to the occurrence of gems and rare minerals in Ceylon, including the remarkable thorianite. An interesting occurrence is described on the Haldummulla estate, where corundum occurs in violet, pink and purplish crystals loose in the soil, and also in blocks of a sillimanite rock. These were not found in place, but doubtless

came from a point not far distant. The sillimanite rocks have been found in certain parts of Ceylon somewhat abundantly in the garnetiferous leptynites. The author remarks: "The sillimanite-bearing rocks have a strong resemblance to the khondalites of Southern India; they do not, however, occur in the same way above the charnockite series, but completely incorporated with it, forming probably bands and lenticular masses; the rocks have, however, been rarely seen *in situ*, and it has not been possible to study closely their relation to the charnockites proper. It must be pointed out that there is a complete transition to the ordinary granulite type. On the one hand, we have a rock composed wholly of sillimanite, and all varieties from this, through quartz-feldspar-sillimanite-garnet schist, to garnetiferous leptynite with very little sillimanite, and ordinary garnetiferous and non-garnetiferous leptynites can be collected."

Intrusive granite rocks which have been called the "Balangoda group" have afforded a number of rare and interesting minerals, including, thorianite, thorite, allanite, baddeleyite, geikielite and cassiterite. The thorianite occurs in moderate quantities near Kondrugala in Bambarabotuwa, Sabaragamuwa. It is found in heavy black crystals, more or less water-worn, associated with zircon and pebbles of ilmenite. It is obtained by the same method used in washing gems, and it is stated that the whole amount thus far removed from Bambarabotuwa is less than 30 cwt., and it is not probable that more than a total of 5 tons could be obtained from the Kuda Pandi-oya valley; two other localities mentioned might yield half a ton additional.

An interesting account is given of the occurrence of gems and the methods of gemming in Ceylon; this is supplemented by some excellent illustrations reproduced from photographs. The gem-bearing gravel, or illam, occurs in beds, patches, or pockets deposited by streams and rivers, and may be found at any depth, up to 120 feet, the greatest depth observed, viz: at Botiyatenna, Rakwana. Where the illam is found in its typical form, it consists largely of white quartz pebbles, ranging in size from a small shot to a football, indeed in all gradations of size up to that of the bowlders associated with the illam.

21. *The Production of Precious Stones in 1904;* by GEORGE F. KUNZ (Extract from Mineral Resources of the United States, U. S. Geol. Survey).—The annual reports in regard to the Production of Precious Stones always contain matter of interest. Of recent discoveries in this country the most important noted are those of Southern California, particularly in San Diego county, which has yielded near Ramona fine blue and white topaz; also rose-colored beryl at Mesa Grande and Pala, and axinite at Bonsall. The colored tourmalines, both in California and Maine, have been mined extensively, and the new locality of peridot at Talklai, Gila Co., Arizona, has yielded large quantities of fine gems. Much interesting information is given in regard to the diamond industry, particularly in South Africa.

22. *Celestite in Canada* (Communicated).—HENRY LAMPARD notes the occurrence of crystals of celestite at Longue Pointe on the Island of Montreal. They are found in a vein, with fibrous structure, in the Trenton limestone near where it is cut by an igneous dike.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *American Association.*—The fifty-fifth annual meeting of the American Association for the Advancement of Science was held at New Orleans during the week beginning Dec. 29, with Prof. C. M. Woodward as President. Six affiliated societies met at the same time. The next meeting of the Association has been appointed for New York City in Convocation week, beginning Dec. 27, 1906. Professor W. H. Welch has been elected President.

2. *Ostwald's Klassiker der exakten Wissenschaften.* Leipzig, 1904 (Wilhelm Engelmann).—The following are the titles of the latest additions to this highly valuable series of scientific classics:

No. 146.—Über die Lösung der unbestimmten Probleme zweiten Grades; von JOSEPH LOUIS LAGRANGE (1768). Pp. 131. Aus dem Französischen übersetzt und herausgegeben von Eugen Netto in Giessen.

No. 147.—Beitrag zur physiologischen Optik; von JOHANN BENEDIKT LISTING. Pp. 52, with portrait and two plates. Herausgegeben von Prof. Dr. Otto Schwarz, Leipzig.

No. 148.—Über das Gedächtnis als eine allgemeine Funktion der organisierten Materie; von EWALD HERING. Pp. 21. Vortrag gehalten in der feierlichen Sitzung der Kaiserlichen Akademie der Wissenschaften in Wien, am XXX Mai, MDCCCLXX.

No. 149.—Tastsinn und Gemeingefühl; von ERNST HEINRICH WEBER. Pp. 156 with portrait. Herausgegeben, von Ewald Hering.

No. 150.—Bestimmung des Brechungs-und Farbenzerstreuungsvermögens verschiedener Glasarten in Bezug auf die Vervollkommung achromatischer Fernröhre; von JOSEPH FRAUNHOFER. Pp. 36, with portrait, 1 plate and 6 text figures. Herausgegeben, von Arthur von Oettingen.

The Science Year Book, with Astronomical, Physical and Chemical Tables, Summaries of Progress in Science, Directory and Diary for 1906 (Second year of issue). Edited by MAJOR B. F. S. BADEN-POWELL. Pp. 208; 365; vi. London, 1905. (King, Sell & Olding, Ltd).—The Preface states that in this issue of the Science Year Book, "a number of additions and alterations have been made. New maps of the Constellations and of the Moon replace the old ones. Maps of Magnetic Variation and Rainfall are added, as are tables of Geology and of the Animal Kingdom. In addition to many new notes, among those in Physics and Chemistry is a table of Spectra. In the Directory, a list of Universities with Professors of Science is included; also a list of Colonial Scientific Societies, and many new names are added to the Biographies."

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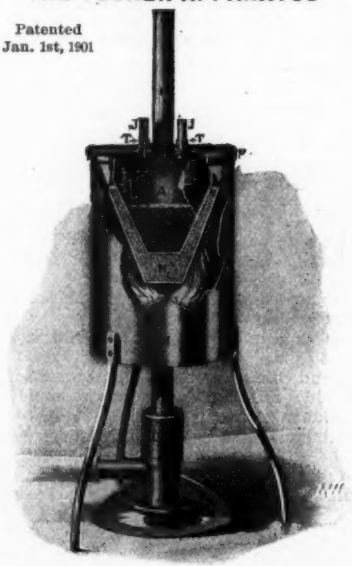

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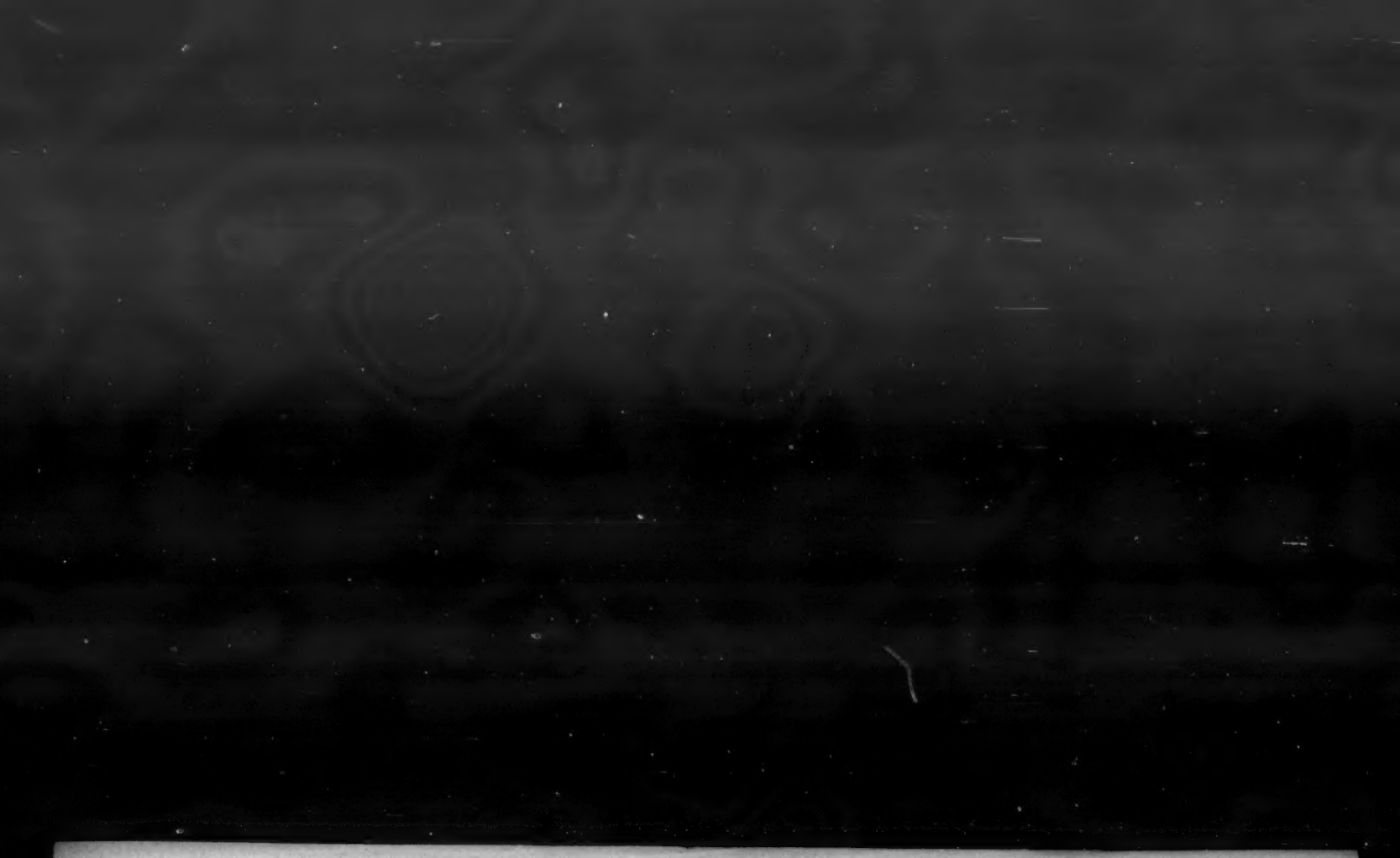
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